TRANSACTIONS

OF

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CONTENTS.

CORRECTIONS.

P. 9. — For $\sum_{i=1}^{i=n}$, read $\sum_{i=1}^{i=i}$.

P. 15, equation (23). — For $(R_{i+1}^5 - R_i^5)$, read $(R_i^5 - R_{i-1}^5)$.

P. 28, equation (53). — For 244, read 2.44.

P. 32, last line. — For $\left(\frac{R_0}{R}\right)$, read $\left(\frac{R_0}{R}\right)^4$.

P. 34, line 11. — For compounded, read compound.

Equation (61). — For $\sum_{i=0}^{i=1}$, read $\sum_{i=0}^{i=i}$.

P. 36, last line but one. — For from, read for.
Foot note. — For 458, read 455.

P. 70, line 16 from top. — For 6, read 8.

P. 77, line 3 from bottom. — For I, read II.

P. 128, line 5 from top. — For *Posidomya*, read *Posidonomya*.
Last line but one. — For *Bucanopis*, read *Bucanopsis*.

P. 218, line 21 from top. — After evidence, insert improperly admitted.

P. 226, line 10 from bottom. — Before locomotive, insert the.

MEMBERS.

1. PATRONS.

Harrison, Edwin........................3747 Westminster pl.

2. ACTIVE MEMBERS.

Adkins, James..............................Park and Vandeventer avs.
Alleman, Gellert..........................Washington University.
Alt, Adolf....................................3036 Locust st.
Andrews, William Edward...........Taylorville, Ill.

Bain, Robert Edward Mather.......900 Locust st.
Bailey, Liberty Hyde ....Ithaca, N. Y.
Baker, Carl F..............................Normal and High School.
Ball, David C...............................27 William st., New York City.
Barck, Carl...................................2715 Locust st.
Bartlett, George M......................215 Pine st.
Bauduy, J. K................................2810 Olive st.
Baumgarten, Gustav...................5227 Washington av.
Becktold, William B....................212 Pine st.
Bernays, A. C..............................3623 Laclede av.
Biebinger, Frederick W..............1421 S. 11th st.
Bixby, William K..........................13 Portland pl.
Boogher, John H..........................4034 Delmar boul.
Bouton, Charles Leonard..............503 Craigie Hall. Cambridge, Mass.
Brannon, Melvin A........................Grand Forks, N. Dak.
Bremer, Ludwig.............................3723 West Pine boul.
Brennan, Martin S........................1414 O'Fallon st.
Brookings, Robert S.....................5125 Lindell av.
Brown, Daniel S............................2212 DeKalb st.
Bryson, John P.............................209 N. Garrison av.
Budgett, Sidney Payne.................1806 Locust st.
Burg, William................................1756 Missouri av.
Burnett, E. C................................University Club.
Busch, Adolphus...........................1 Busch pl.
Busch, Aug. A...............................Busch pl.
Bush, Benjamin Franklin..............Courtney, Mo.

Calvert, Sidney..........................State University, Columbia, Mo.
Carpenter, George O...................Russell and Compton avs.
Carter, Howard..........................Webster Groves, Mo.
Carver, George W......................Tuskegee, Ala.
Chaplin, Winfield S....................3636 West Pine boul.
Chase, E. C..............................3325 Morgan st.
Chauvenet, Louis.......................5501 Chamberlain av.
Chouteau, Charles P...................918 Security bldg.
Chouteau, Pierre.......................912 Security bldg.
Chouteau, Mrs. Pierre...............912 Security bldg.
Compton, P. C..........................4156 Washington boul.
Comstock, T. Griswold..............3401 Washington av.
Conklin, Harry R ....Joplin, Mo.
Coulter, John M........................University of Chicago, Chicago, Ill.
Cramer, Gustav.........................c/o G. Cramer Dry Plate Co.
Crandall, George C....................3558 Lindell av.
Crunden, Frederick Morgan.........Public Library.
Curtis, William S.......................St. Louis Law School.
Cushman, Allerton S..................Harvard University, Cambridge, Mass.

Dameron, Edward Caswell..........Clarksville, Mo.
Davis, H. N..............................56 Vandeventer pl.
Davis, John D...........................421 Olive st.
Diehm, Ferdinand......................1834 Kennett pl.
Dodd, S. M...............................415 Locust st.
Douglas, Archer W ....9th and Spruce sts.
Drake, George S........................64 Vandeventer pl.
Duenckel, F. W.........................3634 Russell av.
Durant, George F......................9 Benton pl.

Eggert, Henry...........................1001 Collinsville av., East St. Louis, Ill.
Eliot, Edward C.........................5468 Maple av.
Eliot, Henry W..........................2635 Locust st.
Engler, Edmund Arthur............Washington University.
Erker, Adolph P........................608 Olive st.
Espenschied, Charles.................3500 Washington av.
Euston, Alexander.....................3730 Lindell boul.
Evers, Edward..........................1861 N. Market st.
Ewing, Arthur E........................3333 Washington av.

Fischel, Washington E................2647 Washington av.
Forbes, Stephen A.....................Urbana, Ill.

Fordyce, John R........................3634 Washington boul.
Forster, Marquard ....2317 S. 13th st.
Francis, David R.......................4421 Maryland av.
French, George Hazen...............Carbondale, Ill.
Frerichs, Frederick W...............4608 S. Broadway.
Frick, John Henry.......................Warrenton, Mo.
Fruth, Otto J.............................3066 Hawthorne boul.
Fry, Frank R..............................3133 Pine st.
Funkhouser, Robert Monroe........3534 Olive st.

Gazzam, James Breading.............514 Security bldg.
Gerling, H. J............................ 4320 Cook av.
Glasgow, Frank A......................3894 Washington boul.
Glasgow, William C...................2847 Washington av.
Goetz, Victor.............................129 Market st.
Goldstein, Max. A......................3702 Olive st.
Goodman, Charles H..................3329 Washington av.
Graham, Benjamin B...................3500 Morgan st.
Graves, William W....................1943 N. 11th st.
Gray, Melvin L..........................3756 Lindell boul.
Grebe, E....................................3839 Russell av.
Green, John ....2670 Washington av.
Gregory, Elisha H......................2525 Lucas av.
Gregory, Elisha H., Jr...............Harvard Medical School,
Boston, Mass.
Grindon, Joseph ....509 N. Theresa av.
Grocott, Willis H.......................1812 Coleman st.
Gurney, James..........................Tower Grove and Magnolia avs.
Guy, William E.........................4380 Westminster pl.

Haarstick, Henry C...................Main and Walnut sts.
Hambach, Gustav *....................Washington University.
Hardaway, W. A........................2922 Locust st.
Hartmann, Rudolph ....14 S. 2d st.
Herthel, Adolph.........................1739 Waverly pl.
Herzog, William.........................3644 Botanical av.
Hirschberg, Francis D................3818 Lindell boul.
Hitchcock, Albert Spear ....Manhattan, Kas.
Hitchcock, Henry ....709 Wainwright bldg.
Holman, M. L............................3744 Finney av.
Holzinger, John Michael............207 W. King st., Winona, Minn.

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* Elected a life-member January 3, 1882.

Hough, Warwick......................3877 Washington av.
Hughes, Charles Hamilton ....3857 Olive st.
Hugunin, F. U..........................1025 Pendleton av.
Huiskamp, John E....................5554 Cabanne av.
Hume, H. Harold......................Lake City, Fla.
Hunicke, Henry August.............3532 Victor st.
Hurter, Julius..........................2346 S. 10th st.
Hyatt, Robert J........................Weather Bureau.

Ives, Halsey C..........................Museum of Fine Arts.

Jackson, Clarence M.................110 Dorsey st., Columbia, Mo.
Jacobs, Arthur I........................2824 Clark av.
Jester, E. T..............................2342 Whittemore pl.
Johnson, J. B...........................4244 Washington boul.
Johnson, Reno De O..................Desloge, Mo.
Jones, Breckinridge..................4010 Lindell boul.

Keiser, Edward H......................Washington University.
Kennett, A. Q...........................2916 Lucas av.
Keyes, Charles R.......................944 Fifth st., Des Moines, Ia.
Kinealy, John H........................Washington University.
King, Goodman..........................78 Vandeventer pl.
Kirchner, Walter C. G...............4234a Easton av.
Kline, George R........................215 Pine st.
Kodis, Theodore........................1806 Locust st.
Krall, George W........................Manual Training School.

Lackland, Rufus J......................1623 Locust st.
Langsdorf, Alexander S..............403 Huestis st., Ithaca, N. Y.
Lazell, Ellis W..........................Spencer, Mass.
Lee, James W............................223 N. 2d st.
Lefevre, George ....State University, Columbia, Mo.
Leighton, George B...................803 Garrison av.
Leighton, George E...................803 Garrison av.
Lemoine, Edwin S.....................3526 Washington av.
Letterman, George W...............Allenton, Mo.
Lichter, John J., Jr...................5305 Virginia av.
Loeb, Hanau Wolf.....................3559 Olive st.
Ludwig, Charles V. F ....1509 Chouteau av.
Lumelius, J. George..................1225 St. Ange av.
Lyon, Hartwell Nelles...............3910 Russell av.

Macbride, T. H ....Iowa City, Ia.
Mack, Charles J.........................113 N. Broadway.

Madill, George A......................4140 Lindell boul.
Mallinckrodt, Edward...............26 Vandeventer pl.
Markham, George Dickson.........4961 Berlin av.
Marx, Christian William............Box 73, Columbia, Mo.
Maserang, Joseph, Jr................Washington and Leffingwell avs.
Mason, Silas C..........................Berea, Ky.
Matthews, Leonard....................300 N. 4th st.
McElwee, L. C......................1113 N. Grand av.
McMillan, William......................25 Portland pl.
Meier, Theodore G....................3938 Washington boul.
Merrell, Albert..........................3814 Washington boul.
Michel, Eugene H......................2721 S. King's Highway.
Miller, Charles F.......................1751 Missouri av.
Monell, Joseph T......................Flat River, Mo.
Moore, Robert..........................61 Vandeventer pl.
More, Louis Trenchard..............University of Cincinnati, Cincinnati, O.
Morton, I. W.............................9th and Spruce sts.
Mottier, David M......................Bloomington, Ind.
Mudd, Harvey G........................2604 Locust st.
Muegge, Aug. H........................2712 Franklin av.
Mueller, Ambrose.....................Webster Groves, Mo.

Nagel, Charles..........................3969 Washington boul.
Nasse, Aug...............................209 N. 2d st.
Nelson, Aven.............................Laramie, Wyom.
Nelson, N. O.............................8th and St. Charles sts.
Niedringhaus, George W............3747 Lindell boul.
Nipher, Francis E......................Washington University.
Norton, J. B. S.........................4159 McRee av.

Oelfcken, Ernst W.................... 3207 Olive st.
Oglevee, Christopher Stoner.......Box 37, Lincoln, Ill.
Olshausen, Ernest P..................1115 Rutger st.
Olshausen, George R..................19 Artillerie st., Berlin, Germany.
O'Reilly, Andrew J ....326 City Hall.
O'Reilly, Robert J......................3411 Pine st.
Outten, W. B...........................Mo. Pacific Hospital.
Overstolz, Herman.....................100 N. Broadway.

Pammel, Louis Hermann............Ames, Ia.
Pantaleoni, Guido......................415 Locust st.
Parker, George Ward.................417 Pine st.
Parsons, Charles........................2804 Pine st.

Pauls, Gustavus........................Eureka, Mo.
Pegram, George H....................195 Broadway, New York City.
Pettus, W. H. H........................2834 Chestnut st.
Pike, Sherman B.........................American Central bldg.
Pitzman, Julius..........................1900 S. Compton av.
Poats, Thomas Grayson.............Clemson College, S. C.
Post, Martin Hayward...............3015 Lucas av.
Preetorius, Emil........................2013 Park av.
Prewitt, Theodore F..................4615 Westminster pl.
Primm, Alexander T., Jr............c/o J. Kennard & Sons.
Pritchett, Henry Smith..............Institute of Technology, Boston, Mass.
Pulsifer, William H...................Newton Centre, Mass.

Quaintance, A. L........................Experiment, Ga.

Randall, John E.........................1910 Olive st.
Ravold, Amand...........................2806 Morgan st.
Reverchon, Julien.......................Box 229, Dallas, Tex.
Robert, E. S...............................1105 Union Trust bldg.
Roberts, Herbert F.....................Washington University.
Robertson, Charles.....................Carlinville, Ill.
Roever, William Henry...............1000 N. Grand av.
Rogers, Herbert F......................c/o Provident Chemical Works.
Rolfs, P. H.................................Clemson College, S. C.
Runge, Edward C........................Supt. Insane Asylum.
Russell, Colton...........................1814 Coleman st.

Sander, Enno...............................129 S. 11th st.
Sargent, Charles Sprague............Jamaica Plain, Mass.
Schmalz, Leopold.........................2824 Shenandoah av.
Schneck, Jacob.............................Mt. Carmel, Ill.
von Schrenk, Hermann................Washington University.
Schroers, John..............................1730 Missouri av.
Schwab, Sidney I.........................2602 Locust st.
Schwarz, Henry............................1723 Chouteau av.
Schweitzer, Paul...........................Columbia, Mo.
Scott, Henry C.............................64 Vandeventer pl.
Seddon, James A..........................1637 Indiana av., Chicago, Ill.
See, Thomas Jefferson Jackson.....Naval Observatory, Washington, D. C.
Selby, Augustine Dawson............Wooster, O.
Senseney, E. M............................2829 Washington av.
Sheldon, Walter L........................4065 Delmar av.

Shepley, John F........................60 Vandeventer pl.
Simmons, E. C........................9th and Spruce sts.
Simmons, W. D........................9th and Spruce sts.
Sluder, Greenfield........................2647 Washington av.
Smith, Arthur George................422 N. Dubuque st., Iowa City, Ia.
Smith, D. S. H........................3646 Washington boul.
Smith. Irwin Z........................87 Vandeventer pl.
Smith, Jared G........................U. S. Dept. Agriculture, Washington, D. C.
Soldan, F. Louis........................3634 Flad av.
Spiegelhalter, Joseph................2166 Lafayette av.
Starr, John E........................258 Broadway, New York City.
Staudinger, B........................3556 Lindell boul.
Stedman, John Moore................Columbia, Mo.
Stevens, Charles D....................1749 S. Grand av.
Stevens, Wyandotte James.........1175 Grand av., Carthage, Mo.
Stocker, George I....................2831 Victor st.
Stone, Charles H........................City Hall.
Strauss, Julius C........................3516 Franklin av.
Stuart, James Lyall....................5346 Maple av.
Sutter, Otto........................3035 Bell av.

Taussig, Albert E....................2318 Lafayette av.
Taussig, William........................3447 Lafayette av.
Teichmann, William C................1141 Market st.
Terry, Robert James....................2726 Washington av.
Thacher, Arthur........................4304 Washington boul.
Thiele, Albert........................2746 Park av.
Thilly, Frank........................601 Hitt st., Columbia, Mo.
Thom, Charles........................806 Conley av., Columbia, Mo.
Thomas, John R........................420 N. 4th st.
Thurman, John S........................416 Lincoln Trust bldg.
Timmerman, Arthur H................2633 Park av.
Tittmann, Harold H....................3726 Washington boul.
Trelease, William........................Mo. Botanical Garden.
Tyler, Elza Edward....................State University, Columbia, Mo.
Tyrrell, Warren Ayres................3620a Folsom av.

Updegraff, Milton........................2505 Wisconsin av., Washington, D. C.

Vallé, Jules F........................3303 Washington av.
Van Ornum, John Lane..............Washington University.
Vickroy, Wilhelm Rees..............2901 Rauschenbach av.

von Schrader, George F............Wainwright bldg.
von Schrader, Otto U................Carleton bldg.

Wall, L. J. W..........................4532 Virginia av.
Walsh, Edward, Jr...................4341 Westminster pl.
Warren, William Homer............1806 Locust st.
Watts, Millard F......................4362 Morgan st.
Weller, Stuart.........................University of Chicago, Chicago, Ill.
Westgate, J. M........................Manhattan, Kas.
Wheeler, H. A.........................3124 Locust st.
Whelpley, Henry Milton............2342 Albion pl.
Whitaker, Edwards...................300 N. 4th st.
Whitten, John Charles..............Columbia, Mo.
Whittier, Charles Thurston..........92 St. James pl., Brooklyn, N. Y.
Widmann, Otto........................Old Orchard, Mo.
Winkelmeyer, Christopher..........3540 Chestnut st.
Winslow, Arthur......................104 W. 9th st., Kansas City, Mo.
Wislizenus, Frederick A............3628 Cleveland av.
Witt, Thomas D........................6th and Olive sts.
Wood, Obadiah M......................3016 Caroline st.
Woodward, Calvin Milton..........3013 Hawthorne boul.

Zahorsky, John........................1460 S. Grand av.

3. Corresponding Members.*

Agard, A. H. 1867.
Agassiz, Alexander. 1866. Cambridge, Mass.
†Agassiz, Louis. 1856.
†Anguiano, Angel. 1885.
Aughey, Samuel. 1876.
Ayres, W. O. 1857.

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* This list contains the names of all persons elected to corresponding membership since the organization of the Academy, with the date of election in each case, and, where it can be given, the present address of living members. Where the Academy has not been in communication with a member for a considerable number of years and has failed to receive a response to communications mailed to his last published address, the latter has been omitted. Persons who can do so are requested to communicate with the corresponding secretary of the Academy concerning errors and omissions in the list.

† Deceased.

†Bache, A. D. 1856.
†Baird, Spencer F. 1860.
†Bandelier, Adolph F., Jr. 1860.
†Barcena, Mariano. 1875.
Barnes, G. W. 1876. San Diego, Cal.
†Barrande, Joachim. 1861.
Barris, Willis H. 1857.
†Beebe, Edward H. 1857.
Behr, Hermann H. 1856. San Francisco, Cal.
†Bent, Silas. 1857.
Berchon, Ernest. 1865.
Bigelow, John M. 1863.
†Bigsby, John J. 1863.
†Billings, E. 1858.
Binney, W. G. 1857. Burlington, N. J.
Blake, James. 1861.
Blatchford, Thomas W. 1857.
Bosquet, J. 1862.
Broadhead, Garland Carr. 1858. Columbia, Mo.
Brown, B. B. 1856.
Bryan, Francis T. 1856.
†Bunsen, Albert. 1863.
†Bunsen, Charles. 1856.
†Bunsen, George. 1856.

†Capellini, Giovanni. 1863.
Case, Francis M. 1863.
†Case, Theodore S. 1885.
del Castillo, Antonio. 1875. Mexico, Mexico.
Clifford J. C. 1871.
Cochrane, J. 1878. Havana, Ill.
Copes, Joseph S. 1873. New Orleans, La.
Coues, Elliott. 1864. Washington, D. C.
Culbertson, Alexander. 1856.

†Dall, Charles H. A. 1857.
†von Danckelman, A. 1885.
Daniels, Edward. 1857.
†Davidson, Thomas. 1858.
Dawson, Alexander. 1856.
Deming, C. M. 1856.
†Dowler, T. Bennett. 1856.

† Deceased.

Dudding, Richard. 1857.	
†Dunglison, Robley. 1856.	
Dyer, F. M. 1877.	Charleston, Mo.
Ehrenberg, Hermann. 1859.	
†Emmons, Ebenezer. 1857.	
†Engelmann, Henry. 1859.	
†Evans, John. 1856.	
†Fendler, Augustus. 1867.	
†Flagg, Willard C. 1857.	
Fleming, R. B. 1857.	
Foster, Mrs. Abner. 1878.	Beardstown, Ill.
Fry, Carey H. 1856.	
Gale, Horace B. 1891.	Natick, Mass.
Galpin, Charles. 1856.	
Gill, Theodore N. 1866.	Washington, D. C.
†Giroux, A. 1856.	
Goodnow, Isaac T. 1865.	
†Goodrich, Hiram P. 1856.	
Green, Samuel M. 1877.	Cape Girardeau, Mo.
de Gregorio, Antonio. 1885.	Palermo, Sicily.
†von Hagenow, Frederick. 1860.	
†Haidinger, Wilhelm. 1860.	
†Hall, James. 1856.	
Hann, Julius. 1881.	Vienna, Austria.
†Harney, William S. 1856.	
†von Hauer, Carl. 1881.	
†Hawn, F. 1858.	
†Hayden, F. V. 1856.	
Henry, F. C. 1856.	
†Henry, Joseph. 1856.	
†Higginbotham, John. 1857.	
Hilgard, Eugene Woldemar. 1860.	Berkeley, Cal.
Hilgard, Gustavus. 1877.	Belleville, Ill.
Hinrichs, Gustavus. 1876.*	
Hitchcock, Charles Henry. 1860.	Hanover, N. H.
Hitchcock, George N. 1876.	San Diego, Cal.
†von Hochstetter, Ferdinand. 1881.	
Hodgkiss, H. 1856.	

* Resigned. † Deceased.

†Holden, Edward. 1856.	
Holden, Edward Singleton. 1881.	New York, N. Y.
Holmes, Nathaniel. 1868. 1883.	Cambridge, Mass.
†Holtzmann, Adolph. 1860.	
Horine, Solomon. 1860.	
Hough, Daniel. 1875.	Indianapolis, Ind.
Hough, Warwick. 1856*.	St. Louis, Mo.
Howland, H. R. 1877.	Buffalo, N. Y.
†Hoy, Philo R. 1857.	
Huguet-Latour, L. A. 1857.	Montreal, Canada.
†Hunt, Thomas Sterry. 1857.	
†Irving, Roland Duer. 1877.	
Irwin, J. T. 1861.	
†Jackson, Charles T. 1861.	
†Jackson, John B. S. 1856.	
†James, John. 1858.	
Johnson, D. M. 1860.	
Johnson, H. 1873.	
Jones, John P. 1874.	Keytesville, Mo.
†Kane, Elisha Kent. 1856.	
Keates, Charles.	Keytesville, Mo.
†King, Henry. 1856.	
Kipp, A. 1856.	
Koelle, John. 1877.	Birkner, Ill.
†de Koninck, L. G. 1877.	
Lane, E. 1857.	
†Lapham, Increase A. 1857.	
†LeConte, John L. 1856.	
Lee, W. J. 1873.	Iron Ridge, Mo.
†Leidy, Joseph. 1856.	
†Lindheimer, Ferdinand. 1856.	
†Locke, John, Jr. 1857.	
†Logan, Sir William E. 1857.	
Lyon, T. Gallatin. 1867.	
†Lyon, Sidney S. 1860.	
†Marcou, Jules. 1860.	
†Marcy, R. B. 1857.	

† Deceased.

* Elected, at his request, to active membership, December 6, 1897.

Marsh, George P. 1857.	
Mayer, Martin. 1865.	
†McAdams, William, Jr. 1859.	
†McClellan, George B. 1857.	
McGregor, A. L. 1857.	
†McMasters, S. G. 1858.	
†Meek, F. B. 1856.	
Meline, James F. 1865.	Washington, D. C.
Morerod, E. R. 1860.	
Mosblech, P. W. 1859.	
†von Mueller, Baron Ferdinand. 1883.	
†Newberry, John Strong. 1861.	
Norris, Benjamin. 1857.	
†Norwood, Charles J. 1875.	
†Norwood, Joseph G. 1856.	
†Owen, Richard. 1862.	
Parker, J. C. 1876.	San Diego Ca.
†Parry, C. C. 1861.	
†Patrick, John J. R. 1876.	
†Pavy, Otto. 1880.	
†Peter, Robert. 1862.	
Phillips, Henry, Jr. 1881.	Philadelphia, Pa.
†Pope, John. 1856.	
†Pratt, George C. 1881.	
†Pratten, Henry. 1856.	
Price, R. B. 1860.	
Putnam, F. W. 1877.	Cambridge, Mass.
Rau, Charles. 1880.	
Rauch, John H. 1856.	
†Reuss, Adolphus. 1856.	
†Riddell, J. L. 1856.	
†Riddell, W. P. 1859.	
†Riley, Charles Valentine. 1880.	
†Robb, James. 1863.	
†Robin, Charles. 1861.	
Russell, John. 1857.	
†Ryland, Kirtley. 1856.	

† Deceased.

Sartwell, Henry P. 1866.	Penn Yan, N. Y.
Sawyer, Amos. 1874.	Hillsboro, Ill.
†von Schlagintweit, Robert. 1869.	
†Schoenich, Henry. 1857.	
†Schultz, C. H. 1860.	
†Seemann, Berthold. 1857.	
†Seyffarth, Gustavus. 1877.	
Sharswood, William. 1859.	
Sheldon, D. S. 1857.	
Shepard, Charles U. 1860.	
Shepherd, John. 1879.	Macon, Mo.
Shimer, Henry. 1864.	Mt. Carroll, Ill.
†Shumard, George G. 1857.	
Sloan, William J. 1860.	
Snyder, John F. 1856.	
Snyder, William. 1856.	
Spencer, Joseph William Winthrop. 1884.	Washington, D. C.
†Squier, E. George. 1860.	
Stanton, Fred. J. 1875.	
Steele, George. 1856.	
Stone, George C. 1881.	New York City, N. Y.
Suess, Eduard. 1858.	Vienna, Austria.
†Swallow, George Clinton. 1856.	
Teft, Jonathan E. 1874.	
†Trécul, Auguste. 1856.	
†Vasey, George. 1861.	
†Vaughan, A. J. 1856.	
Veatch, Charles. 1868.	Keytesville, Mo.
†Vom Rath, Gerhard. 1884.	
Wadsworth, John L. R. 1880.	Collinsville, Ill.
†Warren, G. K. 1856.	
Warriner, Henry A. 1862.	
Weber, J. 1877.	Belleville, Ill.
†Weiss, Adolph. 1861.	
Wells, Lemuel T. 1860.	
Wheeler, G. H. 1856.	
Wheelock, L. P. 1867.	
White, Charles Abiathar. 1860.	Washington, D. C.
White, George. 1857.	

† Deceased.

†Whittlesey, Charles. 1856.
Williams, Doctor. 1857.
†Wilson, George. 1884.
†Winchell, Alexander. 1860.
Woodruff, William T. 1861.
†Worthen, Amos H. 1859.

†Yandell, L. P. 1856.
Yoakum, F. L. 1870. Larissa, Tex.

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† Deceased.

EXCHANGES.*

Africa.

MAURITIUS.

Port Louis.

Royal Alfred Observatory.

North America.

CANADA.

Halifax (*Nova Scotia*).

Nova Scotian Institute of Natural Science.

Hamilton (*Ontario*).

Hamilton Association.

Montreal (*Quebec*).

"Canadian Record of Science."

Natural History Society.

Royal Society of Canada.

Ottawa (*Ontario*).

Geological and Natural History Survey of Canada.

Institut Canadien Français.

Literary and Scientific Society.

Quebec (*Quebec*).

Entomological Society of Canada.

Literary and Historical Society of Quebec.

Université Laval.

St. John (*New Brunswick*).

Natural History Society of New Brunswick.

Toronto (*Ontario*).

Astronomical and Physical Society.

Canadian Institute.

Winnipeg (*Manitoba*).

Manitoba Historical and Scientific Society.

COSTA RICA.

San José.

Central Office of Statistics and Meteorology.

Museo Nacional.

GUATEMALA.

Guatemala.

Secretaria de Fomento.

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* Conformed, as far as practicable, to the International Exchange List of 1897, of the Smithsonian Institution.

MEXICO.

Mexico.

Ministerio de Fomento, Colonizacion, etc.

Museo Nacional.

Sociedad Científica "Antonio Alzate."

Sociedad Mexicana de Geografia y Estadistica.

Sociedad Mexicana de Historia Natural.

Tacubaya.

Observatorio Astronómico Nacional.

SAN SALVADOR.

San Salvador.

Observatorio Meteorológico y Astronómico.

UNITED STATES.

Albany (*N. Y.*).

New York State Library.

New York State Museum of Natural History.

Ann Arbor (*Mich.*).

University of Michigan Library.

Auburn (*Ala.*).

Agricultural Experiment Station.

Austin (*Tex.*).

Geological Survey of Texas.

State Library of Texas.

Texas Academy of Science.

Baltimore (*Md.*).

"American Chemical Journal."

Johns Hopkins University, — Biological Library.

Johns Hopkins University Library.

Maryland Academy of Sciences.

Maryland Geological Survey.

Peabody Institute Library.

Baton Rouge (*La.*).

State University Library.

Boston (*Mass.*).

American Academy of Arts and Sciences.

Massachusetts Horticultural Society.

Public Library.

Society of Natural History.

Brooklyn (*N. Y.*).

The Brooklyn Library.

Brookville (*Ind.*).

Society of Natural History.

UNITED STATES — *Continued.*

Buffalo (*N. Y.*).

Society of Natural Sciences.

Cambridge (*Mass.*).

Entomological Club.

Harvard College Library.

Harvard College Observatory.

Museum of Comparative Zoology.

Peabody Museum of American Archaeology and Ethnology.

Chapel Hill (*N. C.*).

Elisha Mitchell Scientific Society.

Charleston (*S. C.*).

Elliott Society of Science and Art.

Charlotteville (*Va.*).

University of Virginia Library.

Chicago (*Ill.*).

Academy of Sciences.

Field Columbian Museum.

Historical Society.

John Crerar Library.

"The Monist."

Public Library.

University of Chicago Library.

Cincinnati (*O.*).

Society of Natural History.

Cleveland (*O.*).

Geological Society of America.

Columbia (*Mo.*).

State University Library.

Columbus (*O.*).

Ohio State University Library.

Davenport (*Ia.*).

Academy of Natural Sciences.

Denver (*Col.*).

Colorado Scientific Society.

Des Moines (*Ia.*).

Iowa Academy of Science.

Geneva (*N. Y.*).

Agricultural Experiment Station.

Golden (*Col.*).

State School of Mines.

UNITED STATES — *Continued.*

Good Hope (*Ill.*).

"American Antiquarian."

Granville (*O.*).

Denison Scientific Association.

Hanover (*N. H.*).

Dartmouth College Library.

Houston (*Tex.*).

State Geological and Scientific Association.

Indianapolis (*Ind.*).

Indiana Department of Geology and Natural Resources.

Ithaca (*N. Y.*).

Cornell University Agricultural Experiment Station.

Cornell University Library.

Jefferson City (*Mo.*).

State Geological Survey.

State Library.

Kansas City (*Mo.*).

Academy of Science.

Knoxville (*Tenn.*).

East Tennessee University Library.

University of Tennessee Library.

University of Tennessee Scientific Magazine.

Lawrence (*Kan.*).

Kansas University Library.

Lincoln (*Neb.*).

Nebraska University, — Department of Zoology.

Nebraska University Library.

Louisville (*Ky.*).

Public Library of Kentucky.

Madison (*Wis.*).

Washburn Observatory.

Wisconsin Academy of Science, Arts and Letters.

Wisconsin Historical Society.

Wisconsin University Library.

Meriden (*Conn.*).

Scientific Association.

Milwaukee (*Wis.*).

Natural History Society of Wisconsin.

Naturhistorischer Verein.

Public Museum.

UNITED STATES — *Continued.*

Minneapolis (*Minn.*).

Geological and Natural History Survey of Minnesota.

Minnesota Academy of Natural Science.

Mount Hamilton (*Cal.*).

Lick Observatory.

New Brighton (*N. Y.*).

Natural Science Association of Staten Island.

New Brunswick (*N. J.*).

Agricultural Experiment Station.

New Haven (*Conn.*).

"American Journal of Science."

Connecticut Academy of Science.

Yale University Astronomical Observatory.

Yale University Library.

New York (*N. Y.*).

Academy of Science.

American Geographical Society.

American Museum of Natural History.

Botanical Garden.

Chemical Society.

Linnaean Society of New York.

Mathematical Society.

Public Library.

Torrey Botanical Club.

Northfield (*Minn.*).

Carleton College Observatory.

Oberlin (*O.*).

Oberlin College Library.

Pasadena (*Cal.*).

Academy of Sciences.

Peoria (*Ill.*).

Scientific Association.

Philadelphia (*Pa.*).

Academy of Natural Science.

American Entomological Society.

American Philosophical Society.

Commercial Museum.

"Journal of Comparative Medicine and Surgery."

"Journal of Pharmacy."

Library Company.

Numismatic and Antiquarian Society.

UNITED STATES — *Continued.*

Philadelphia (*Pa.*) — *Continued.*

Pennsylvania Woman's Medical College.

Pharmaceutical Association.

"Polyclinic."

Wagner Free Institute of Science.

Zoological Society.

Pittsburg (*Pa.*).

Carnegie Museum.

Portland (*Me.*).

Society of Natural History.

Poughkeepsie (*N. Y.*).

Vassar Brothers Institute.

Princeton (*N. J.*).

Museum of Geology and Archaeology.

Rochester (*N. Y.*).

Academy of Science.

Rolla (*Mo.*).

Missouri School of Mines.

Salem (*Mass.*).

Essex Institute.

Peabody Academy of Science.

San Diego (*Cal.*).

Society of Natural History.

San Francisco (*Cal.*).

Astronomical Society of the Pacific.

California Academy of Science.

Geographical Society of California.

State Mining Bureau.

Technical Society of the Pacific Coast.

Santa Barbara (*Cal.*).

Society of Natural History.

South Bend (*Ind.*).

Northern Indiana Historical Society.

Springfield (*Ill.*).

Geological Survey of Illinois.

Springfield (*Mo.*).

Drury College Library.

St. Louis (*Mo.*).

"Journal of Ophthalmology."

Mercantile Library.

Missouri Botanical Garden.

UNITED STATES — *Continued.*

St. Louis (*Mo.*) — *Continued.*

Public Library.

St. Louis University Library.

Washington University Library.

Stanford University (*Cal.*).

Leland Stanford Junior University Library.

Topeka (*Kas.*).

Kansas Academy of Science.

Trenton (*N. J.*).

Natural History Society.

Urbana (*Ill.*).

State Laboratory of Natural History.

Urbana (*O.*).

Central Ohio Scientific Association.

Washington (*D. C.*).

Philosophical Society.

Smithsonian Institution.

United States Bureau of Education.

United States Bureau of Ethnology.

United States Coast and Geodetic Survey.

United States Department of Agriculture.

——, Division of Entomology.

——, Weather Bureau.

United States Fish Commission.

United States Geological Survey.

United States National Museum.

United States Naval Observatory.

United States War Department, — Engineer Department, U. S. A.

Wooster (*O.*).

Agricultural Experiment Station.

Worcester (*Mass.*).

American Antiquarian Society.

Society of Antiquity.

WEST INDIES.

Gordon Town (*Jamaica*).

Public Gardens and Plantations.

Kingston (*Jamaica*).

Institute of Jamaica.

South America.

Argentine Republic.

Buenos Aires.

Museo Nacional de Buenos Aires.

Sociedad Científica Argentina.

Departamento Nacional de Estadistica.

Cordoba.

Academia Nacional de Ciencias.

Observatorio Nacional Argentino.

Brazil.

Rio de Janeiro.

Instituto Historico, Geographico y Ethnographico.

Museu Nacional.

Nautical Observatory.

São Paulo.

Commissão Geographica e Geologica.

Chile.

Santiago.

Deutcher Wissenschaftlicher Verein.

Sociedad Científica de Chile.

Uruguay.

Montevideo.

Museo Nacional.

Asia.

India.

Bombay.

Natural History Society.

Calcutta.

Asiatic Society of Bengal.

Indian Museum.

Japan.

Tōkyō.

Deutsche Gesellschaft für Natur-und Völkerkunde Ost-Asiens.

Imperial University of Japan.

Netherlands Indies.

Batavia (*Java*).

Magnetic and Meteorological Observatory.

Straits Settlements.

Singapore.

Royal Asiatic Society, — Straits Branch.

Australasia.

New South Wales.

Sydney.

Australian Museum.

Geological Survey of New South Wales,—Department of Mines.

Linnean Society of New South Wales.

Royal Society of New South Wales.

Queensland.

Brisbane.

Geographical Society of Australasia, — Queensland Branch.

Queensland Museum of Natural History.

South Australia.

Adelaide.

Royal Geographical Society,—South Australian Branch.

Royal Society of South Australia.

Tasmania.

Hobarton.

Royal Society of Tasmania.

Victoria.

Melbourne.

National Museum of Victoria.

Royal Society of Victoria.

Europe.

Austria-Hungary.

Bistritz (*Transylvania*).

Gewerbeschule.

Brünn (*Moravia*).

K. K. Mährisch Landwirthschafts-Gesellschaft.

Naturforschender Verein.

Budapest (*Hungary*).

" Ethnologische Mittheilungen aus Ungarn."

K. Magyar Természettudományi Társulat.

(*R. Hungarian Society of Natural Sciences.*)

K. Magyar Tudományos Egyetem.

(*R. Hungarian University.*)

K. Ungar. Geologische Anstalt.

Magyar Nemzeti Museum.

(*Hungarian National Museum.*)

Magyar Tudományos Akademia.

(*Hungarian Academy of Sciences.*)

Ornithologische Gesellschaft.

Austria-Hungary — *Continued.*

Graz (*Styria*).

Naturwissenschaftlicher Verein für Steiermark.

Steiermärkischer Industrie und Gewerbe Verein.

Hermannstadt (*Transylvania*).

Siebenbürgischer Verein für Naturwissenschaften.

Verein für Siebenbürgische Landes-Kunde.

Klagenfurth (*Carinthia*).

Naturhistorisches Landesmuseum für Kärnten.

Klausenburg (*Transylvania*).

Medicinische Naturwissenschaftliche Section des Siebenbürgischen Museum Vereins.

Krakau (*Galicia*).

Académie des Sciences de Cracovie.

Laibach (*Carniola*).

Krainsches Landesmuseum Rudolfinum.

Leipa (*Bohemia*).

Nord-Böhmischer Excursions-Club.

Lemberg (*Galicia*).

Société Scientifique de Chevtchènko.

Linz (*Upper Austria*).

Museum Francisco-Carolinum.

Prag (*Bohemia*).

K. Böhmische Gesellschaft der Wissenschaften.

Naturwissenschaftlicher Verein "Lotos."

Pressburg (*Hungary*).

Verein für Naturkunde.

Reichenberg (*Bohemia*).

Verein der Naturfreunde.

Salzburg (*Salzburg*).

Städtisches Museum Carolino-Augusteum.

Trencsin (*Hungary*).

Naturwissenschaftlicher Verein des Trencsiner Comitates.

Trieste (*Istria*).

Museo Civico di Storia Naturale.

Società Adriatica di Scienze Naturali.

Wien (*Lower Austria*).

Anthropologische Gesellschaft.

Kaiserliche Akademie der Wissenschaften.

K. K. Central-Anstalt für Meteorologie und Erd-Magnetismus.

AUSTRIA-HUNGARY — *Continued.*

Wien (*Lower Austria*) — *Continued.*

K. K. Geographische Gesellschaft.

K. K. Geologische Reichsanstalt.

K. K. Naturhistorisches Hof Museum.

K. K. Zoologisch-Botanische Gesellschaft.

Niederoesterreichischer Forst-Verein.

Oesterreichischer Touristen-Club.

Oesterreichischer Reichs-Forst-Verein.

Verein zur Förderung des Landwirthschaftlichen Versuchswesens.

Verein zur Verbreitung Naturwissenschaftlicher Kenntnisse.

BELGIUM.

Bruxelles.

Académie Royale des Sciences, des Lettres et des Beaux Arts de Belgique.

Observatoire Royal.

Société Belge de Géographie.

Société Belge de Microscopie.

Société Entomologique de Belgique.

Société Malacologique de Belgique.

Société Royale de Botanique de Belgique.

Société Royale Linnéenne de Bruxelles.

Société Scientifique de Bruxelles.

Société Scientifique Flammarion d'Ixelles.

Liége.

Société Géologique de Belgique.

Louvain.

Université Catholique.

DENMARK.

Kjöbenhavn [Copenhagen].

Kongelige Danske Videnskabernes Selskab.

FRANCE.

Abbeville (*Somme*).

Société d'Emulation.

Alais (*Gard*).

Société Scientifique et Littéraire.

Amiens (*Somme*).

Académie des Sciences, Lettres, et Arts.

Société Linnéenne du Nord de la France.

Angers (*Maine-et-Loire*).

Société des Etudes Scientifiques.

FRANCE — *Continued.*

Arras (*Pas-de-Calais*).

Académie des Sciences, Lettres, et Arts.

Autun (*Saône-et-Loire*).

Société d'Histoire Naturelle.

Auxerre (*Yonne.*).

Société des Sciences Historiques et Naturelles.

Avranches (*Manche*).

Société Académique du Cotentin.

Bar-le-Duc (*Meuse*).

Société des Lettres, Sciences et Arts.

Bastia (*Corsica*).

Société des Sciences Historiques et Naturelles de a Corse.

Bayeux (*Calvados*).

Société d'Agriculture, Sciences, Arts et Belles-Lettres.

Bayonne (*Basses-Pyrénées*).

Société des Sciences et Arts.

Besançon (*Doubs*).

Société d'Emulation du Doubs.

Bordeaux (*Gironde*).

Académie Nationale des Belles-Lettres, Sciences et Arts.

Société Linnéenne de Bordeaux.

Société des Sciences Physiques et Naturelles.

Caen (*Calvados*).

Académie Nationale des Sciences, Arts et Belles-Lettres.

Faculté des Sciences de Caen, — Laboratoire de Géologie.

Société Linnéenne de Normandie.

Chalons-Sur-Marne (*Marne*).

Société d'Agriculture, Commerce, Sciences et Arts du Département de la Marne.

Chambéry (*Savoie*).

Académie des Sciences, Belles-Lettres et Arts deSavoie.

Cherbourg (*Manche*).

Société Académique.

Société Nationale des Sciences Naturelles et Mathématiques.

Dijon (*Côte-d'Or*).

Académie des Sciences, Arts et Belles-Lettres.

France — *Continued.*

Draguignan (*Var*).

Société des Etudes Scientifiques et Archéologiques.

Elbeuf (*Seine-Inférieure*).

Société d'Enseignement Mutuel des Sciences Naturelles.

Epinal (*Vosges*).

Société d'Emulation du Département des Vosges.

Evreux (*Eure*).

Société Libre d'Agriculture, Sciences, Arts et Belles-Lettres du Département de l'Eure.

Grenoble (*Isère*).

Académie Delphinale.

Faculté des Sciences.

Lyon (*Rhône*).

Académie des Sciences, Belles-Lettres et Arts.

Bibliothèque Universitaire.

Société des Sciences Industrielles.

Société Linnéenne de Lyon.

Marseille (*Bouches-du-Rhône*).

Académie des Sciences, Lettres et Arts.

Société Scientifique Industrielle.

Montauban (*Tarn-et-Garonne*).

Académie des Sciences, Belles-Lettres et Arts du Département de Tarn-et-Garonne.

Montpellier (*Hérault*).

Académie des Sciences et Lettres.

Nancy (*Meuthe-et-Moselle*).

Académie de Stanislas.

Société des Sciences.

Nevers (*Nièvre*).

Société Nivernaise des Letters, Sciences et Arts.

Nice (*Alpes-Maritimes*).

Société des Lettres, Sciences et Arts des Alpes Maritimes.

Niort (*Deux-Sèvres*).

Société de Statistique, Sciences et Arts des Deux-Sèvres.

Paris.

Académie des Sciences.

Association Française pour l'Avancement des Sciences.

Ecole Normale Supérieure.

Ecole Polytechnique.

France — *Continued.*

Paris — *Continued.*

"Feuille des Jeunes Naturalistes."

Institut National Agronomique.

Institut Pasteur.

Journal de Micrographie.

Musée Guimet.

Museum d'Histoire Naturelle.

Revue Archéologique.

Revue Géographique Internationale.

Société Académique Indo-Chinoise.

Société d'Anthropologie.

Société de Biologie.

Société Entomologique de France.

Société d'Ethnographie.

Société Zoologique de France.

Pau (*Basses-Pyrénées*).

Société des Sciences, Lettres et Arts.

Perpignan (*Pyrénées-Orientales*).

Société Agricole, Scientifique et Litteraire des Pyrénées-Orientales.

Reims (*Marne*).

Académie Nationale de Reims.

Société des Sciences Naturelles.

Rouen (*Seine-Inférieure*).

Académie des Sciences, Belles-Lettres et Arts.

Société des Amis des Sciences Naturelles.

Saint Brieuc (*Côtes-du-Nord*).

Société d'Emulation des Côtes-du-Nord.

Saint Dié (*Vosges*).

Société Philomathique Vosgienne.

Saint Dizier (*Haute-Marne*).

Société des Lettres, des Sciences, des Arts, de l'Agriculture et de l'Industrie.

Toulouse (*Haute-Garonne*).

Académie des Sciences, Inscriptions et Belles-Lettres.

Association Pyénéenne, et Union des Sociétés Savantes du Midi.

Bibliothèque de la Faculté des Sciences.

Vendôme (*Loir-et-Cher*).

Société Archéologique, Scientifique et Littéraire du Vendômois.

France — *Continued.*

Vitry-le-François (*Marne*).

Société des Sciences et Arts.

Germany.

Altenburg (*Saxe-Weimar*).

Naturforschende Gesellschaft des Osterlands.

Augsburg (*Bavaria*).

Naturwissenschaftlicher Verein für Schwaben und Neuburg.

Bamberg (*Bavaria*).

Naturforschende Gesellschaft.

Berlin (*Prussia*).

Botanischer Verein der Provinz Brandenburg.

Deutsche Chemische Gesellschaft.

Deutsche Geologische Gesellschaft.

Deutsche Landwirthschaftliche Gesellschaft.

Gesellschaft für Erdkunde.

Gesellschaft Naturforschender Freunde.

Kaiserliches Gesundheits-Amt.

Königlich Preussische Akademie der Wissenschaften.

Königliches Botanisches Museum.

"Naturae Novitates."

Verein zur Beförderung des Gartenbaues in den Königlich Preussischen Staaten.

Bonn (*Prussia*).

Naturhistorischer Verein der Preussischen Rheinlande, Westfalens und des Regierungsbezirks Osnabrück.

Braunschweig (*Brunswick*).

Verein für Naturwissenschaften.

Bremen.

Geographische Gesellschaft.

Naturwissenschaftlicher Verein.

Breslau (*Silesia*).

Schlesische Gesellschaft für Vaterländische Cultur.

Chemnitz (*Saxony*).

Naturwissenschaftliche Gesellschaft.

Danzig (*Prussia*).

Naturforschende Gesellschaft.

Darmstadt (*Hesse*).

Verein für Erdkunde.

Dresden (*Saxony*).

Gesellschaft für Natur-und Heilkunde.

GERMANY — *Continued.*

Dresden (*Saxony*) — *Continued.*

Königliches Zoologisches und Anthropologisch-Ethnographisches Museum.

Naturwissenschaftliche Gesellschaft "Isis."

Verein für Erdkunde.

Dürkheim (*Bavaria*).

Naturwissenschaftlicher Verein "Pollichia."

Elberfeld (*Prussia*).

Naturwissenschaftlicher Verein von Elberfeld und Barmen.

Emden (*Prussia*).

Naturforschende Gesellschaft.

Erfurt (*Prussia*).

Akademie Gemeinnütziger Wissenschaften.

Frankfurt-am-Main (*Prussia*).

Physikalischer und Aerzlicher Verein.

Senckenbergische Naturforschende Gesellschaft.

Verein für Geographie und Statistik.

Frankfurt-an-der-Oder (*Prussia*).

Naturwissenschaftlicher Verein des Regierungsbezirkes.

Freiburg-im-Breisgau (*Baden*).

Naturforschende Gesellschaft.

Giessen (*Hesse*).

Oberhessische Gesellschaft für Natur- und Heilkunde.

Görlitz (*Prussia*).

Naturforschende Gesellschaft.

Göttingen (*Prussia*).

Königliche Societät der Wissenschaften.

Greifswald (*Prussia*).

Geographische Gesellschaft.

Naturwissenschaftlicher Verein von Neuvorpommern und Rügen.

Halle-an-der-Saale (*Prussia*).

Kaiserliche Leopoldinisch-Carolinische Deutsche Akademie der Naturforscher.

Landwirthschaftliches Institut der Universität.

Naturforschende Gesellschaft.

Verein für Erdkunde.

"Zeitschrift für die Gesammten Naturwissenschaften."

GERMANY — *Continued.*

Hamburg.

Naturwissenschaftlicher Verein, Hamburg-Altona.

Hanau (*Hesse*).

Wetterauische Gesellschaft für die Gesammte Naturkunde.

Hannover (*Prussia*).

Naturhistorische Gesellschaft.

Heidelberg (*Baden*).

Naturhistorisch-Medicinischer Verein.

Jena (*Saxe-Weimar*).

Geographische Gesellschaft für Thüringen.

"Jenaische Zeitschrift für Medizin und Naturwissenschaften."

Karlsruhe (*Baden*).

Naturwissenschaftlicher Verein.

Kassel (*Prussia*).

Verein für Naturkunde.

Kiel (*Prussia*).

Königliche Sternwarte.

Naturwissenschaftlicher Verein für Schleswig-Holstein.

Universitäts Bibliothek.

Königsberg (*Prussia*).

Königliche Physikalisch-Oekonomische Gesellschaft.

Landshut (*Bavaria*).

Botanischer Verein.

Leipzig (*Saxony*).

Dr. Felix Flügel, 39 Sidonien Strasse.

Königlich Sächsische Gesellschaft der Naturwissenschaften.

Naturforschende Gesellschaft.

Verein für Erdkunde.

"Zoologischer Anzeiger."

Lüneburg (*Prussia*).

Naturwissenschaftlicher Verein.

Magdeburg (*Prussia*).

Naturwissenschaftlicher Verein.

Mannheim (*Baden*).

Verein für Naturkunde.

Marburg (*Prussia*).

Gesellschaft zur Beförderung der Gesammten Naturwissenschaften.

GERMANY — *Continued.*

Metz (*Lorraine*).

Académie de Metz.

Société d'Histoire Naturelle.

Verein für Erdkunde.

München (*Bavaria*).

Deutscher und Oesterreichischer Alpen-Verein, — Section München.

Königlich Bayerische Akademie der Wissenschaften.

Münster (*Westphalia*).

Provinzial-Verein für Wissenschaft und Kunst.

Nürnberg (*Bavaria*).

Naturhistorische Gesellschaft.

Offenbach (*Baden*).

Verein für Naturkunde.

Osnabrück (*Prussia*).

Naturwissenschaftlicher Verein.

Passau (*Bavaria*).

Naturhistorischer Verein.

Posen (*Prussia*).

Historische Gesellschaft für die Provinz Posen.

Regensburg (*Bavaria*).

Historischer Verein für die Oberpfalz.

Königlich Bayerische Botanische Gesellschaft.

Naturwissenschaftlicher Verein.

Rostock (*Mecklenburg*).

Verein der Freunde der Naturgeschichte in Mecklenburg. (c/o Mineralogisches Museum.)

Stettin (*Prussia*).

Entomologischer Verein.

Stuttgart (*Würtemberg*).

Mathematisch-Naturwissenschaftlicher Verein in Würtemberg.

Verein für Vaterländische Naturkunde in Würtemberg.

Thorn (*Prussia*).

Copernicus Verein für Wissenschaft und Kunst.

Wiesbaden (*Prussia*).

Verein für Naturkunde.

Würzburg (*Bavaria*).

Physikalisch-Medizinische Gesellschaft.

GREAT BRITAIN AND IRELAND.

Alnwick (*England*).

Berwickshire-Naturalists' Club.

Belfast (*Ireland*).

Naturalists' Field Club.

Bristol (*England*).

Naturalists' Society.

Dublin (*Ireland*).

Royal Dublin Society.

Royal Irish Academy.

Edinburgh (*Scotland*).

Geological Society.

Royal Physical Society.

Royal Scottish Society of Arts.

Royal Society of Edinburgh.

Glasgow (*Scotland*).

Geological Society.

Natural History Society.

Philosophical Society.

Halifax (*England*).

Yorkshire Geological and Polytechnical Society.

Kew (*England*).

Royal Botanic Gardens.

Leeds (*England*).

Philosophical and Literary Society.

Liverpool (*England*).

Biological Society.

London (*England*).

British Museum.

Entomological Society.

"Nature." (c/o The Macmillan Co.)

Royal Geographical Society.

Royal Microscopical Society.

Royal Society.

Manchester (*England*).

"Journal of Conchology." (c/o Owens College.)

Literary and Philosophical Society.

Microscopical Society.

Newcastle-upon-Tyne (*England*).

Natural History Society of Northumberland, Durham, and Newcastle-upon-Tyne.

York (*England*).

Yorkshire Philosophical Society.

ITALY.

Bologna.

Accademia delle Scienze dell' Istituto di Bologna.

Catania.

Accademia Gioenia di Scienze Naturali.

Firenze [Florence].

Biblioteca Nazionale Centrale.

"Nuovo Giornale Botanico Italiano."

R. Accademia Economico-Agraria dei Georgofili.

R. Istituto di Studi Superiori.

Genova [Genoa].

Accademia delle Scienze, Lettere ed Arti.

Museo Civico di Storia Naturale.

Società Ligustica di Scienze Naturali e Geografiche.

Società dei Naturalisti.

Milano [Milan].

Fondazione Scientifica Cagnola.

R. Istituto Lombardo di Scienze e Lettere.

Società Italiana di Scienze Naturali.

Modena.

R. Accademia di Scienze, Lettere ed Arti.

Napoli [Naples].

Accademia Pontaniana.

R. Accademia delle Scienze e Belle Lettere.

R. Accademia delle Scienze Fisiche e Mathematiche.

Società di Naturalisti.

Padova [Padua].

R. Accademia di Scienze, Lettere ed Arti.

Società Veneto-Trentina di Scienze Naturali.

Palermo.

Orto Botanico.

Società d'Acclimazione e di Agricoltura in Sicilia.

Pisa.

Società Toscana di Scienze Naturali.

Roma.

Biblioteca Nazionale Vittorio Emanuele.

Istituto d'Igiene Sperimentale dell' Università.

R. Accademia dei Lincei.

R. Comitato Geologico d' Italia.

R. Stazione Chimico Agraria.

Società Italiana delle Scienze.

Siena.

R. Accademia dei Fisiocritici.

ITALY — *Continued.*

Torino [Turin].

Accademia Reale delle Scienze.

Club Alpino Italiano, — Sezione Torino.

Museo di Zoologia e di Anatomia Comparata della R. Università.

Venezia [Venice].

R. Istituto Veneto di Scienze, Lettere et Arti.

LUXEMBURG.

Luxemburg.

Institut Luxembourgeois, — Section des Sciences Naturelles.

NETHERLANDS.

Amsterdam.

Genootschap ter Bevordering van Natuur- Genees- en Heelkunde.

K. Akademie van Wetenschappen.

K. Nederlandsch Aardrijkskundig Genootschap.

K. Zoologische Genootschap "Natura Artis Magistra."

's Gravenhage [The Hague].

Die Triangulation von Java.

Haarlem.

Fondation de P. Teyler van der Hulst.

Hollandsche Maatschappij van Wetenschappen.

Leiden.

Nederlandsche Dierkundige Vereeniging.

Rijks Observatorium.

Middelburg.

Zeeuwsch Genootschap van Wetenschappen.

Rotterdam.

Bataafsch Genootschap der Proefondervindelijke Wijsbegeerte.

Utrecht.

K. Nederlandsche Meterologisch Instituut.

Provinciaal Utrechtsch Genootschap van Kunsten en Wetenschappen.

Zwolle.

Overijsselsche Vereeniging tot Ontwikkeling van Provinciaale Welvaart.

NORWAY.

Bergen.

Bergens Museum.

NORWAY — *Continued.*

Christiania.

K. Norske Frederiks Universitet.

Trondhjem.

K. Norske Videnskabernes Selskab.

Tromsö.

Tromsö Museum.

PORTUGAL.

Lisbôa [Lisbon].

Academia Real das Sciencias.

Sociedade de Geographia.

Porto [Oporto].

Academia Polytechnica.

ROUMANIA.

Bukarest.

Academia Română.

"Buletinul Societath de Sciinte Fizice."

RUSSIA.

Derpt [Dorpat].

Derptskoie Obshchestvo Iestestvo-Ispytatelei. (*Society of Naturalists.*)

K. Livländische Oekonomische Gesellschaft.

Naturforscher Gesellschaft.

Helsingfors.

Sällskap pro Fauna et Flora Fennica.

Kazan.

Imp. Kazanskii Universitet.

Kief.

Kiefskoie Obshchestvo Iestestvo-Ispytatelei. (*Society of Naturalists.*)

Moskva [Moscow].

Imp. Moskofskoie Obshchestvo Iestestvo-Ispytatelei. (*Society of Naturalists.*)

Meteorological Observatory of the Agricultural Academy.

Odessa.

Novo-Rossiiskoie Obshchestvo Iestestvo-Ispytatelei. (*Society of Naturalists.*)

Riga.

Obshchestvo Iestestvo-Ispytatelei. (*Society of Naturalists.*)

RUSSIA — *Continued.*

Sankt-Peterburg [St. Petersburg].

Imp. Akademia Nauk.
(*Academy of Sciences.*)

Imp. Biblioteka.

Imp. Russkoie Geograficheskoie Obshchestvo.
(*Geographical Society.*)

Imp. Sankt-Peterburgskii Botanicheskii Sad.
(*Botanical Garden.*)

Imp. Sankt-Peterburgskoie Mineralogicheskoie Obshchestvo.
(*Mineralogical Society.*)

Institut Impérial de Médicine Expérimentale.

Tiflis.

Magnitnaia i Meteorologicheskaia Observatoria.
(*Magnetic and Meteorological Observatory.*)

SPAIN.

Barcelona.

Real Academia de Ciencias y Artes.

Córdoba.

Academia Nacional de Ciencias Exactas.

Madrid.

Observatorio de Madrid.

R. Academia de Ciencias Exactas, Fisicas y Naturales.

Sociedad Española de Historia Natural.

SWEDEN.

Lund.

K. Universitet.

Stockholm.

Biologiska Förening.

"Entomologiska Tidsskrift."

K. Svenska Vetenskaps Akademie.

National Historical Museum.

Upsala.

K. Vetenskaps Societet.

Universitets Mineralogisk-Geologisk Institutionen.

SWITZERLAND.

Aarau.

Aargauische Naturforschende Gesellschaft.

Mittelschweizerische Geographisch-Commercielle Gesellschaft.

SWITZERLAND — *Continued.*

Basel.

Naturforschende Gesellschaft.

Bern.

Naturforschende Gesellschaft.

Schweizerische Naturforschende Gesellschaft.

Chur.

Naturforschende Gesellschaft Graubündens.

Frauenfeld.

Thurgauische Naturforschende Gesellschaft.

Fribourg,

Société Fribourgeoise des Sciences Naturelles.

Genève.

Institut National Genevois.

Société de Physique et d'Histoire Naturelle.

Lausanne.

Bibliothèque Cantonale et Universitaire.

Musée d'Histoire Naturelle.

Société Vaudoise des Sciences Naturelles.

Neuchâtel.

Société des Sciences Naturelles.

St. Gall.

Naturwissenschaftliche Gesellschaft.

Zürich.

"Concilium Bibliographicum."

Eidgenossensche Polytechnische Schule.

Naturforschende Gesellschaft.

Schweizer Alpen-Club.

Schweizerischer Forst-Verein.

THE ACADEMY OF SCIENCE OF ST. LOUIS.

ORGANIZATION.

The Academy of Science of St. Louis was organized on the 10th of March, 1856, in the hall of the Board of Public Schools. Dr. George Engelmann was the first president.

CHARTER.

On the 17th of January following, a charter incorporating the Academy was signed and approved, and this was accepted by vote of the Academy on the 9th of February, 1857.

OBJECTS.

The act of incorporation declares the object of the Academy to be the advancement of science and the establishment in St. Louis of a museum and library for the illustration and study of its various branches, and provides that the members shall acquire no individual property in the real estate, cabinets, library, or other of its effects, their interest being usufructuary merely.

The Constitution, as adopted at the organization meeting and amended at various times subsequently, provides for holding meetings for the consideration and discussion of scientific subjects; taking measures to procure original papers upon such subjects; the publication of transactions; the establishment and maintenance of a cabinet of objects illustrative of the several departments of science, and a library of works relating to the same; and the establishment of relations with other scientific institutions. To encourage and promote special investigation in any branch of science, the formation of special sections under the charter is provided for.

MEMBERSHIP.

Members are classified as active members, corresponding members, honorary members, and patrons. Active membership is limited to persons interested in science, though they need not of necessity be engaged in scientific work, and they alone conduct the affairs of the Academy, under its Constitution. Persons not living in the city or county of St. Louis, who are disposed to further the objects of the Academy by original researches, contributions of specimens, or otherwise, are eligible as corresponding members. Persons not living in the city or county of St. Louis are eligible as honorary members by virtue of their attainments in science. Any person conveying to the Academy the sum of one thousand dollars or its equivalent becomes eligible as a patron.

Under the By-Laws, resident active members pay an initiation fee of five dollars and annual dues of six dollars. Non-resident active members pay the same initiation fee, but annual dues of three dollars only. Patrons, and honorary and corresponding members, are exempt from the payment of dues. Patrons and all active members not in arrears are entitled to one copy each of each publication of the Academy issued after their election.

Since the organization of the Academy, 904 persons have been elected to membership, of whom, at the present time, 286 are carried on the active list. One patron, Mr. Edwin Harrison, has been elected. The present list of corresponding members includes 205 names.

OFFICERS AND MANAGEMENT.

The officers, who are chosen from the active members, consist of a President, two Vice-Presidents, Recording and Corresponding Secretaries, Treasurer, Librarian, three Curators, and two Directors. The general business management of the Academy is vested in a Council composed of the President, the two Vice-Presidents, the Recording Secretary, the Treasurer and the two Directors.

The office of President has been filled by the following well-known citizens of St. Louis, nearly all of whom have been eminent in some line of scientific work: George Engelmann, Benjamin F. Shumard, Adolphus Wislizenus, Hiram A. Prout, John B. Johnson, James B. Eads, William T. Harris, Charles V. Riley, Francis E. Nipher, Henry S. Pritchett, John Green, Melvin L. Gray, and Edmund A. Engler.

MEETINGS.

The regular meetings of the Academy are held at its rooms, 1600 Locust Street, at 8 o'clock, on the first and third Monday evenings of each month, a recess being taken between the meeting on the first Monday in June and the meeting on the third Monday in October. These meetings, to which interested persons are always welcome, are devoted in part to the reading of technical papers designed for publication in the Academy's Transactions, and in part to the presentation of more popular abstracts of recent investigation or progress. From time to time public lectures, calculated to interest a larger audience, are provided for in some suitable hall.

LIBRARY.

After its organization, the Academy met in Pope's Medica College, where a creditable beginning had been made toward the formation of a museum and library, until May, 1869, when the building and museum were destroyed by fire, the library being saved. The library now contains 13,624 books and 9,869 pamphlets, and is open during certain hours of the day for consultation by members and persons engaged in scientific work.

PUBLICATIONS AND EXCHANGES.

Ten thick octavo volumes of Transactions have been published since the organization of the Academy, and widely distributed. Two quarto publications have also been issued, one from the Archaeological section, being a contribution to the archaeology of Missouri, and the other a report of the observations made by the Washington University Eclipse Party of 1889. The Academy now stands in exchange relations with 560 institutions or organizations of aims similar to its own.

MUSEUM.

Since the loss of its first museum, in 1869, the Academy has lacked adequate room for the arrangement of a public museum, and, although small museum accessions have been received and cared for, its main effort of necessity has been concentrated on the holding of meetings, the formation of a library, the publication of worthy scientific matter, and the maintenance of relations with other scientific bodies, through its active membership, which includes many business and professional men who are interested in the work and objects of the Academy, although not themselves investigators.

December 31, 1900.

RECORD.

From January 1, 1900, to December 31, 1900.

January 8, 1900.

President Engler in the chair, nineteen persons present.

The nominating committee reported that 122 ballots had been counted, and the following officers for 1900 were declared duly elected: —

President	Edmund A. Engler.
First Vice-President	D. S. H. Smith.
Second Vice-President	M. H. Post.
Recording Secretary	William Trelease.
Corresponding Secretary	Joseph Grindon.
Treasurer	Enno Sander.
Librarian	Gustav Hambach.
Curators	Gustav Hambach,
	Julius Hurter,
	Hermann von Schrenk.
Directors	Amand Ravold,
	H. W. Eliot.

The President delivered an address on the condition of the Academy and its work during the year 1899.*

The Treasurer submitted his annual report, showing invested funds to the amount of $4,400.00 and a balance of $2,239.13 carried forward to the year 1900, of which $2,000.00, derived from a former investment, awaited reinvestment.†

The Librarian submitted his annual report. ‡

Part II of a paper by Dr. T. J. J. See, on the temperature of the sun and the relative ages of the stars and nebulae, was read by title and referred to the Council.

Mr. A. S. Langsdorf described the methods of determining the rates of vibration of sounding bodies, with special

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* Transactions **9**: xxvii. † Transactions **9**: xxxi. ‡ Transactions **9**: xxxi.

reference to the calibration of tuning forks, illustrating his remarks by the use of the apparatus employed.

Professor E. A. Engler discussed the locus of the intersection of a line through the focus making a constant angle with the tangent to a parabola.

Dr. William H. Warren, of St. Louis, was elected to active membership.

Nine persons were proposed for active membership.

JANUARY 22, 1900.

President Engler in the chair, fifty-four persons present.

The resignations of Messrs. F. F. Gottschalk, G. C. Kinsman and A. T. Terry were reported by the Council, which further reported that Dr. O. Widmann, for some years treated as a corresponding member, had at his request been added to the list of non-resident active members, and that at the request of a committee of the Engineers' Club of St. Louis the President had appointed a committee of three* for conference with said committee and other committees which might be appointed by representative bodies to consider the action necessary to secure the filtration of the water supply of St. Louis.

A paper by Mr. Charles Robertson, entitled Some Illinois bees, was presented and read by title, and referred to the Council with a view to its publication.

Mr. William D. Denton addressed the Academy on Butterflies and their mimicry, illustrating his remarks by a series of beautifully prepared and mounted specimens.

Mr. Gustav Cramer, Dr. E. H. Gregory, Mr. R. J. Hyatt, Dr. Charles F. V. Ludwig, Dr. E. W. Oelfcken, Mr. Herbert F. Roberts and Mr. James Lyall Stuart, of St. Louis, and Professors T. H. Macbride, of Iowa City, Iowa, and Louis Trenchard More, of Lincoln, Nebraska, were elected to active membership.

Seven persons were proposed for active membership.

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* The members of this committee were Mr. I. W. Morton, Dr. Amand Ravold, and Dr. E. H. Keiser.

February 5, 1900.

President Engler in the chair, about two hundred and fifty persons present.

A series of microscopic objects showing some of the technical applications of the microscope, was exhibited under the direction of Dr. H. M. Whelpley, with the assistance of Dr. R. J. Terry (anatomy), Dr. Amand Ravold (bacteriology), Dr. Ludwig Bremer (blood examination), Mr. H. F. Roberts (botany), Dr. H. von Schrenk (diseases of forest trees), Mr. O. H. Elbrecht (drug adulterations), Mr. Victor Goetz (flour inspection), Mr. C. F. Baker (insects parasitic on man), Dr. Otto A. Wall, Jr. (living protoplasm), Mr. Robert Benecke (microphotography and photographic dry plate testing), Dr. G. Hambach (mineralogy), Dr. Adolph Alt (photomicrography), Dr. Hartwell N. Lyon (physiology), Mr. F. W. Maas (seed adulterations), Mr. William K. Ilhardt (spice adulterations), Mr. Peter J. Weber, Jr. (textile fibers), and Dr. G. C. Crandall (trichina). Through the courtesy of the Historical Society, the rooms of that Society were thrown open to the members of the Academy and their guests, and the Society's important collections were examined with interest while the special demonstration of the evening was in progress.

Mr. George W. Niedringhaus and Professor F. Louis Soldan, of St. Louis, were elected to active membership.

February 19, 1900.

President Engler in the chair, forty-three persons present.

The acceptance of the resignations of Dr. M. A. Bliss and Mr. Alfred Clifford, and the addition of the following institutions to the exchange list of the Academy, were reported by the Council: Carnegie Museum; Leland Stanford Junior University; Mathematisch-naturwissenschaftlicher Verein, Stuttgart; Medicinisch-naturwissenschaftliche Gesellschaft, Jena; Nord Böhmischer Excursions-Club; Northern Indiana Historical Society; Ohio State University; Royal Geographical Society of Australia, South Australian Branch; University of Pennsylvania, Free Museum; University of Tennessee Scientific Magazine; Upsala Universitet, Mineralogisk Geologisk Institutionen.

Professor Patrick Geddes, of University College, Dundee, delivered an address on a plan for increasing the educational value of expositions, in which he traced the increasingly complex relation of the world to science and the rapidly increasing need of co-ordination of the sciences, and then gave a concise account of the purposes which it is hoped to realize and the methods to be adopted by the International Association for the Advancement of Science, Art, and Education, which grew out of the meetings of the British and French Associations for the Advancement of Science last autumn, and which is to hold its first international assembly at the Paris Exposition in the course of the present year, the purpose of the Association, — recognizing the wealth of instructive material brought together by the great transient museums, the world's fairs, — being the fullest possible utilization of the educational facilities so brought together. Honorable D. R. Francis spoke further on the subject presented by Professor Geddes, especially in its bearing on the World's Fair which it is proposed to hold in St. Louis, in celebration of the centennial anniversary of the Louisiana purchase.

A paper by Dr. G. A. Miller, on the primitive substitution groups of degree ten, was presented by title.

Professor J. L. Van Ornum, late of the United States Engineer Corps, spoke on the sanitary cleaning of a city, as exemplified by Cienfuegos, Cuba, explaining the conditions found by the United States Army on taking possession of that city, and the thoroughness with which the streets, court yards and cesspools were cleansed by the Engineer Corps, which also charged itself with the betterment of the city water supply. A diagram which the speaker had prepared showed that in addition to a very marked lowering of the death rate which attended the supply of an abundance of wholesome food, on the occupation of Cienfuegos, there had been a decrease of considerably over fifty per cent. in the weekly death rate, directly attributable to the sanitary cleansing of the city; and he further stated that since this work had been done, yellow fever, which before that time had been endemic in Cienfuegos, had been absent from the city.

Mr. Arthur I. Jacobs, Mr. Joseph Maserang, Jr., and Mr. George Ward Parker, of St. Louis, Mr. H. R. Conklin, of Joplin, Missouri, and Professor C. W. Marx, of Columbia, Missouri, were elected to active membership.

Four persons were proposed for active membership.

March 5, 1900.

President Engler in the chair, forty-three persons present.

The death of Mr. Hugo Kromrey and the resignations of Mr. George W. Flersheim and Mr. Carl Kinsley were reported by the Council.

A paper by Professor A. S. Hitchcock, entitled Studies on subterranean organs. II. Some dicotyledonous herbaceous plants of Manhattan, Kansas, was presented and read in abstract by Mr. J. B. S. Norton, and was illustrated by an abundance of specimens, which were passed about for the inspection of the audience.

Mr. J. S. Thurman addressed the Academy on liquid air.

Dr. J. K. Bauduy, Dr. E. Grebe, Mr. William E. Guy and Dr. John Zahorsky, of St. Louis, were elected to active membership.

Five persons were proposed for active membership.

March 19, 1900.

President Engler in the chair, fifty-eight persons present.

Dr. H. von Schrenk exhibited some burls on the white spruce (*Picea Canadensis*). The burls, unlike most of those so far known, are almost round, and are covered with smooth bark. They grow of various sizes, and occur on the trunk and branches of a group of spruces limited to a small area. The wood fibers are arranged in annual rings; they differ from normal wood fibers because of their thinner walls and greater internal diameter, giving the wood a spongy character. Long rows of secondary resin passages occur in each ring.

The largest burls, which are from one to three feet in diameter, have rows of long holes within each ring. These holes are diamond-shaped in cross-section, the longer diameter extending radially. Between the holes the wood fibers are compressed tangentially. The speaker explained that the holes must have resulted from an excessive radial pressure exerted from without, probably by the bark. No holes were found where the bark pressure had been released, i. e., where the bark had burst. These results were not in harmony with the findings as to bark pressure reached by Krabbe. The speaker described the way in which these burls form by excessive growth, induced by a wound or branch stump.

Professor F. E. Nipher exhibited stereopticon slides made from a large number of photographic negatives which had been taken by the electric spark from a Holtz machine. The negatives show a complete picture of the object acted upon by the spark, and also show the electrical radiations in the field around the object photographed.

The plates were greatly over-exposed to light before they were used. They were allowed to lie fully exposed in a well lighted room for from one to nine days. The best results are obtained by darkening the room when the electrical image is produced. Light is found to counteract the electrical effects when their action is simultaneous and also when it follows the electrical exposure. The pictures are developed in the dark room, by the light of an incandescent lamp. When the negative begins to fog, it is taken nearer to the lamp, and it at once clears up. All of these methods are in total disregard of all ordinary photographic procedure. Cramer's crown plates were used and the developing solution is that in common use in photography.

The result which is most interesting from a scientific point of view is shown on twelve negatives which reveal ball lightning effects. Ball lightning is to the electrician what the sea serpent is to the zoologist. It has often been seen, but never by those who are most competent to study and describe it, and all efforts to produce ball lightning effects by artificial means have hitherto failed. But these twelve negatives show with perfect distinctness discharges of this character. They could be seen while they were being photographed. They looked like little spheres of light, which traveled over a non-conducting plate, forming the insulation of a condenser. They traveled very slowly among the sparks of the ordinary disruptive discharge. Their speed was usually at the rate of an inch in three or four minutes. Their tracks showed with the greatest sharpness among the more indistinct flashes of miniature lightning. They sometimes jump for a quarter to a third of an inch, with such quickness that the eye can hardly follow them. Five or six such spheres of light sometimes appear at once, each following its own track. Sometimes one will cross a track previously traced by another, but it never follows the track of another.

By proper illumination of the room, the effects of the spark discharge can be nearly obliterated in the negative, but the paths of the ball discharges are not materially affected. One negative thus treated had been exposed for thirty-five minutes, and the ball lightning tracks were most elaborate. The branching network of lines must have been produced by hundreds of these little spheres.

The same result can be attained by fixing the negatives without any developing process. Everything then vanishes from the plate but the tracks of the ball discharges.

Professor Nipher stated that this phenomenon could not be identified as the same thing as ball lightning, since the latter had not been studied. But it responds to the same decription in many ways. As soon as the ball lightning effects appear, the behavior of the machine changes in a very remarkable way.

Mr. Koch exhibited an electric fire annunciator.

Mr. Victor Goetz and Rev. James W. Lee, of St. Louis, Professor George Lefevre and Mr. Charles Thom, of Columbia, Missouri, and Professor C. S. Oglevee, of Lincoln, Illinois, were elected to active membership.

Six persons were proposed for active membership.

April 2, 1900.

President Engler in the chair, twenty-six persons present.

The resignations of Mr. W. P. Eberlein and Dr. Friedrich Meier were reported by the Council.

A paper by Dr. H. von Schrenk, entitled A severe sleet-storm, and relating to a study of the injury to trees and shrubs by an unusually severe recent ice storm, was presented and read by title.

Dr. W. H. Warren delivered an address on recent investigations with reference to the production of perfumes, giving an outline of the progress in the chemistry of these products. For the most part these substances are high boiling oils. Formerly these oils, which are complex mixtures of several compounds, were obtained exclusively from flowers, but recently some of the essential principles have been produced by chemical means, whereas other artificial perfumes are mere imitations. With a few exceptions the essential principles, which give the perfumes their value, belong to a complex class of organic compounds known as the terpenes. The terpenes are the reduction products of cymol. The molecule is characterized by the presence of an atomic linking such as is found in the hydrocarbon ethylene, and the determination of the exact location of these ethylene linkings constitutes a difficulty in studying the terpenes.

It is found also that nearly every substance having the properties of a perfume has in its molecule certain atomic groups whose presence exerts a marked influence on the odor. Among the more important of these may be mentioned the aldehyde, ketone, ester, ether and alcohol group.

Besides those terpenes, which have the ring-structure in the molecule, there are substances which have long chains of carbon atoms. Apparently such products should be classified with fatty compounds, but so closely do they resemble the terpenes in their properties and chemical behavior that they are placed with them instead. Citral or geranial, an aldehyde found in largest quantity in oil of lemon-grass, is such a substance. Citral is of importance because it is the starting point in the synthesis of ionone, the artificial violet perfume.

The wonderful progress in our knowledge of the terpenes and of their derivatives is the work of scarcely more than ten or fifteen years. There is great activity still, and among those chemists who have taken a prominent part in the labor should be mentioned Wallach, Baeyer and Tiemann.

Dr. Sidney I. Schwab, of St. Louis, Professor S. Calvert, of Columbia, Missouri, Professor George Hazen French, of Carbondale, Illinois, Professor David M. Mottier, of Bloomington, Indiana, Professor W. J. Stevens, of Carthage, Missouri, and Professor Frank Thilly, of Columbia, Missouri, were elected to active membership.

Eight persons were proposed for active membership.

April 16, 1900.

President Engler in the chair, twenty-three persons present.

Mr. Herbert F. Roberts addressed the Academy on the structure and physiology of the cell in the plant organism. The history and development of cytology as a special field in biology was traced, and the origin of the various theories of cell organization was indicated. The development of various theories respecting the centrosome and its role in cell division was discussed, the homologues of the centrosome to be found in ciliated cells and spermatazoa being indicted. After a review of the processes of cell division and their attendant phenomena, the methods of study of mitoses in plants and their proper illustration was considered. A great need exists for more accurate processes of reproduction than is afforded by plates made from camera lucida drawings. The latter are always more or less diagrammatic, and are apt to be modified by the personal bias of the investigator. Unconsciously the personal equation enters in. This is seen in recent work on the existence of the centrosome in higher plants. The difficulty referred to can be overcome by the employment of photomicrography. This has been made use of to a limited extent by zoologists in the study of mitoses, but apparently scarcely at all by botanists. The speaker showed forty prints from photomicrographic negatives showing mitoses in rhizomes of *Erythronium albidum*, and in microspore mother cells and microspores in *Lilium Philadelphicum* and *Pinus laricio*, and megaspores in *Lilium Canadense*. The possibility which photomicrography affords, of giving structural details with relative fidelity, was illustrated by these photographs and by lantern slides.

Mr. Guido Pantaleoni, of St. Louis, Professor L. H. Bailey, of Ithaca, New York, Professor M. A. Brannon, of Grand Forks, North Dakota, Professor C. M. Jackson, of Columbia, Missouri, Professor S. C. Mason, of Berea, Kentucky, Professor Aven Nelson, of Laramie, Wyoming, Mr. Gustavus Pauls, of Eureka, Missouri, and Professor A. G. Smith, of Iowa City, Iowa, were elected to active membership.

Four persons were proposed for active membership.

May 7, 1900.

President Engler in the chair, twenty-three persons present.

Mr. Charles Epenschied presented an address on modern flour milling, tracing the history of the preparation of grain for human food, the developments since 1865, when it was discovered that "middlings," when properly cleaned, could be reground to the best of flour, and the introduction of chilled steel rolls to replace the older millstones, so that to-day a good mill separates practically all the flour in a grain of wheat in its most perfect form, and is always automatic in operation. It was stated that while larger mills are in operation, the most economical mill in use at the present time is that having a daily capacity of about one thousand barrels of flour.

Dr. H. von Schrenk made some remarks concerning the propagation of fruit trees, particularly the apple, illustrating by a large number of specimens the methods of budding and root-grafting which are used for commercial purposes, and discussing at some length the question of the quality of the root system obtained for the new plant by the various modes of propagation.

Professor F. E. Nipher exhibited some photographic negatives on glass, and spoke briefly on the relation between negative and positive in photographic plates, showing that there is a certain relation between intensity of actinic light acting on the plate during exposure and during development, as a result of which a greatly overexposed plate may be developed into a positive instead of a negative, by allowing access of a limited quantity of light during development, while a plate which has been very briefly exposed may in the same manner be developed into a positive by a proportionate increase in the light allowed to fall on it during development,— a neutral or zero point, in which the plate is completely fogged, being passed in each instance.

Mr. G. Pauls exhibited a number of beautiful caterpillars, the larvae of *Euphydryas phaeton*, which does not appear to have been hitherto recorded as occurring in Missouri, although Scudder reports it from adjoining States. The food plant on which these were found was a species of *Gerardia*.

Dr. H. von Schrenk exhibited a burl on the branch of Mississippi scrub pine, caused by a rust fungus, *Peridermium cerebrum*, which was in excellent fruit.

Mr. Pierre Chouteau, Mrs. Pierre Chouteau and Dr. W. B. Outten, of St. Louis, and Professor John H. Frick, of Warrenton, Missouri, were elected to active membership.

Two persons were proposed for active membership.

May 21, 1900.

President Engler in the chair, twenty-four persons present.

A paper by Dr. Adolph Alt, entitled Original contributions concerning the glandular structures appertaining to the human eye and its appendages, was presented by title and referred to the Council.

Dr. M. A. Goldstein read a paper on the physiology of voice production, in which he discussed three essential factors in the production of voice, the motor force, the organ of sound, and the resonators. The essential features presented may be summarized as follows: (1) All elements carefully considered, the best form of breathing applicable to voice production and singing is the rational combination of the costal with the diaphragmatic type. Reserve force in breathing is best attained by deep inspiration, fixation of the distended diaphragm and thorax, and control of these muscles while tone is produced. (2) To facilitate vocalization, the larynx should never be tightly contracted by the muscles of the throat, especially in the production of the registers. (3) On the resonating cavities, their proper conformation and position in relation to the vibrating cords and larynx, depend the quality and timbre of the voice, so that the careful and proper placing of tones is perhaps the most essential factor in voice production.

Professor F. E. Nipher read a short communication on the zero photographic plate, to which reference was made at the meeting of May 7 and in his paper published as Volume X, No. 6, of the Academy's Transactions.

The zero plate is one upon which a photographic image has been made, but which will develop no image in a bath placed in light of given candle power, at a distance of one meter from the source. For example, if the developing bath is twenty centimeters from a sixteen-candle lamp, a Cramer isochromatic plate, such as is called "instantaneous," held for ninety seconds at a distance of one meter from the lamp, will be a zero plate. With an opaque stencil over the plate when placed in a printing frame, during the exposure, there will develop a positive of holes through the stencil if the exposure is longer, and a negative if the exposure is shorter.

If a fresh plate is exposed in our camera, with full opening, to a brilliantly lighted street scene for one minute, it will develop as a positive in that same bath. This time can be somewhat reduced, but the least time needed has not yet been determined. It is evident that part of this minute is used in producing a zero plate. It is furthermore clear that different parts of the plate will arrive at the zero condition at different times. The exposure may be arrested at a time when the strongly lighted white background of a sign-board will develop white as a positive and when the black letters will also show white as a negative.

It has been found that when a plate is uniformly exposed over its whole surface to the extent that nothing would have developed had it been covered by a stencil, this plate may then be placed in a camera and exposed in the ordinary way, and a perfect positive will develop in the bath to which it has been adapted. This preliminary spoiling of the plate for developing a negative is a very advantageous preparation for taking a positive. It shortens the time of exposure, and insures that a positive shall be obtained over all parts of the plate. It is not yet known how short the camera exposures may be made, but the present indications are that they will be as short as those now made in the taking of negative pictures.

It is currently believed by photographers that in a positive plate the object has "printed its picture" upon the plate. This is an entire misconception of the process. It is true that in an exposure of long duration an image shows on the plate before it is placed in the bath. But this image is blackest where the light has acted most. It is a negative. This picture disappears in the developing bath when illuminated. The plate becomes perfectly clear. The positive picture then develops, exactly as a negative would under ordinary conditions.

Mr. J. B. S. Norton presented some notes on the flora of the southwestern United States. Maps were shown indicating the parts of this region and others not well represented in herbaria, as compared with other sections of the country. Among other interesting features of the Southwest was mentioned the production of many different forms or closely related species in the isolated mountains surrounded by deserts. This was compared with insular conditions and illustrated by the mountain forms of *Euphorbia*. Specimens of some new species from Southwest Missouri were also shown.

Mr. Walter C. G. Kirchner, of St. Louis, and Professor William Edward Andrews, of Taylorville, Illinois, were elected to active membership.

Two persons were proposed for active membership.

June 4, 1900.

President Engler in the chair, sixteen persons present.

Dr. Warren B. Outten addressed the Academy on the true interpretation of sound, presenting what he believed to be a new principle in acoustics, and describing a method of re-enforcing sounds by means of various membranes.

Two persons were proposed for active membership.

October 15, 1900.

President Engler in the chair, sixteen persons present.

The addition of the Department of Zoology of the University of Nebraska, and Naturae Novitates, of Berlin, to the exchange list of the Academy was reported by the Council.

The Secretary laid before the Academy a portion of a femur [supposed to be that of a bison], presented by Mr. E. A. Hermann, Sewer Commissioner of the city, who reported that it had been found in a four-foot gravel seam under twenty-two feet of clay, in the excavation now being made for the Tower Grove storm sewer, between the Frisco and Missouri Pacific railways, 1,934 feet east of King's Highway. On motion, the thanks of the Academy were extended to Mr. Hermann for this addition to the Academy's collections.

Mr. William H. Roever discussed the subject of the establishment of the method of least squares, in an exhaustive and masterful manner which does not admit of brief abstract.

A paper by Professor F. E. Nipher, entitled Positive photography, with special reference to eclipse work, and a paper by the same author, entitled The frictional effect of railway trains upon the air, were presented and read by title.

Mr. C. F. Baker exhibited a collection which he had prepared for the National Museum, representing nearly all of the species of fleas thus far known to science.

Dr. Hartwell N. Lyon, of St. Louis, Professor John M. Holzinger, of Winona, Minnesota, Mr. Ambrose Mueller, of Webster Groves, Missouri, and Mr. Julien Reverchon, of Dallas, Texas, were elected to active membership.

Four persons were proposed for active membership.

NOVEMBER 5, 1900.

President Engler in the chair, nineteen persons present.

It was reported by the Council that in accordance with Articles XII and XIII of the By-Laws the following names had been canceled from the list of members: H. C. Frankenfield, W. H. Hammon, John M. Holmes, John A. James James, John Pickard, and William J. Seever.

Dr. T. Kodis delivered an address on electro-chemical theories of animal electricity, analyzing the theories which in the present state of knowledge seem possible as accounting for the origin of electrical currents in animal nerve tissue, and reaching the conclusion that the only tenable theory is that of chemical differences in the contents of the components of the body.

Messrs. Marquard Forster, A. Nasse and Herbert F. Rogers, of St. Louis, and Professor T. G. Poats, of Clemson College, South Carolina, were elected to active membership.

Three persons were proposed for active membership.

NOVEMBER 19, 1900.

President Engler in the chair, nineteen persons present.

Mr. C. F. Baker exhibited a large amount of living and preserved material, including microscopic preparations, illustrative of American Isopods and Amphipods, accompanying the demonstration by a short résumé of the work thus far done on Crustacea, particularly on these two groups, and making some interestingly suggestive remarks on the peculiar affinities of a number of the species found in deep wells or hot springs.

Dr. Amand Ravold presented an abstract of the results reached in some recent bacteriological examinations of water from the Illinois, Mississippi and Missouri rivers, particularly a series of cultures made under aseptic conditions from the contents of the digestive tract of sixty-eight fish of thirteen species and the soft-shelled turtle, from points in the Mississippi and Illinois rivers a short distance above Grafton. In sixty-nine per cent. of the fish examined, the *Bacillus coli-communis*, which is commonly accepted as an index of the presence and amount of sewage contamination in potable waters, was present in the digestive tract in quantity, and cultures showed that this *Bacillus* thrives and multiplies greatly in these contents in cultures kept at the normal body temperature of the fish. The fact that this species, which does not multiply freely in river water at similar temperatures, appears to multiply in this way in the intestines of fish and reptiles, was pointed out as introducing into the biological analysis of the water of rivers and lakes a new factor, of uncertain quantity but tending to destroy confidence in the occurrence and abundance of *Bacillus coli-communis* in water as an indication of the degree to which it has been contaminated by the faecal discharges of human beings and domestic animals. Dr. Ravold stated that in each of the examinations made, the *Bacillus*, when isolated, had been carried through all of the cultures by which *coli-communis* is differentiated from related species with which, in the absence of these tests, it might easily be confused.

Mr. George I. Stocker, of St. Louis, was elected to active membership.

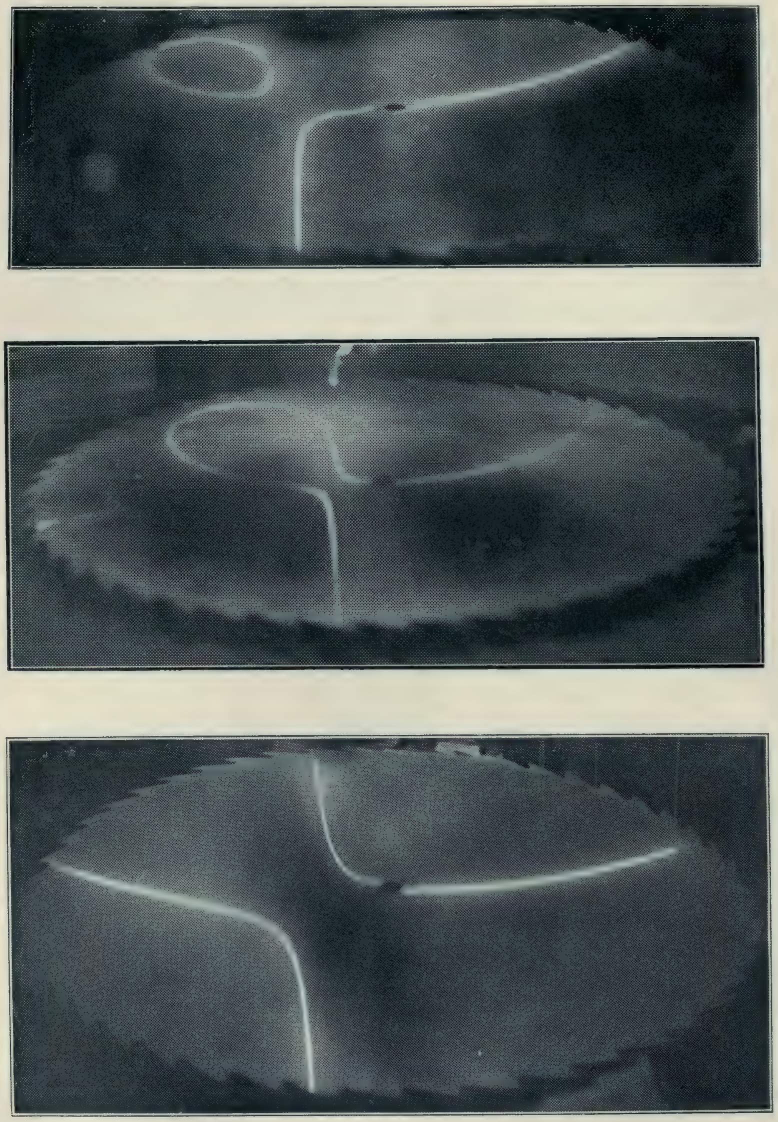
One person was proposed for active membership.

December 3, 1900.

President Engler in the chair, fifteen persons present.

The resignation of Mr. Henry Branch and the addition to the exchange list of the Société Scientifique de Chevtchènko, Lemberg, Austria, and the Indiana Department of Geology and Natural Resources, Indianapolis, Indiana, were reported by the Council, which also announced its authorization of the purchase of the paleontological collection of the late Dr. L. P. Yandell, containing many types, and of particular value as complementary to the Shumard collection now the property of Washington University, it being the expectation of the Council that payment for this collection could be made by means of contributions from members, without encroaching on the current or reserve funds of the Academy.

Mr. William H. Roever, of Washington University, read a paper on brilliant points and loci of brilliant points. The



LOCI OF BRILLIANT POINTS.

paper gave the analytical conditions which define the brilliant point of a surface, the brilliant point of a space curve, the brilliant point of a plane curve and the brilliant point in space of two dimensions, when the source of light is such that the incident rays are normal to a given surface and the recipient is such that the reflected rays are normal to another given surface. Formulae were also given for the important special case in which the source and recipient are points. The paper also contained a general method for finding the equations of the locus of the brilliant points of a moving or variable surface and curve, together with a number of applications. Such loci may often be perceived when an illuminated polished surface is rapidly moved, as when a wheel with a polished spoke is rapidly rotated. Another interesting example in loci of brilliant points is that of a circular saw which has been polished with emery in a lathe and thus received a great number of concentric circular scratches. The locus of the brilliant points of this family of scratches was shown in this paper to be a curve of the fourth degree. In the special case when the point, source of light, and the eye of the observer (the point recipient) are in a plane through the axis of the saw, the curve degenerates into a circle and two coincident straight lines. Accompanying the abstract is a photogram of the saw curve. In this case the optical center of the camera lens is the point recipient. Other interesting facts and a number of geometrical constructions were also given in this paper.

Messrs. Green, Baumgarten and Nipher, were elected a committee for the nomination of officers for the year 1901.

Mr. Joseph T. Monell, of Flat River, Missouri, Mr. Elza Edward Tyler, of Columbia, Missouri, and Mr. J. M. Westgate, of Manhattan, Kansas, were elected to active membership.

One person was proposed for active membership.

December 17, 1900.

President Engler in the chair, forty-six persons present.

The nominating committee reported the following list of candidates for 1901: —

President	Edmund A. Engler.
First Vice-President	D. S. H. Smith.
Second Vice-President	M. H. Post.
Recording Secretary	William Trelease.
Corresponding Secretary	Hermann von Schrenk.
Treasurer	Enno Sander.
Librarian	G. Hambach.
Curators	G. Hambach, Julius Hurter, Robert J. Terry.
Directors	H. W. Eliot, Adolph Herthel.

A paper by Mr. F. C. Baker, entitled A revision of the Limnaeas of northern Illinois, was presented and read by title.

Dr. O. Widmann read an interesting account of the great St. Louis crow-roost, in which were embodied many facts concerning the life-history and habits of the common crow.

Professor F. E. Nipher gave an account of some of his recent results in positive photography. He has now found that hydrochinone baths of normal strength may be used. The formula given in each box of Cramer plates yields good results, if the mixed bath is diluted with water to one-third strength. The potassium bromide may be left out, and one drop of concentrated hypo solution must be added for each ounce of diluted bath. The hypo has a most wonderful effect. With the same bath, plates may be developed as positives, in the dark room or in direct sunlight. He had even started the developing of a plate in a dark room, where it progressed very slowly, but very satisfactorily, continued the operation in diffused daylight in an adjoining room, and finished the operation in direct sunlight. The process was accelerated by the light, but did not appear to be otherwise changed by the change in illumination. The resulting picture could not be distinguished from those produced by ordinary methods. This picture was shown by means of the lantern.

A box of Cramer's "Crown," "Banner" or "Isochromatic" plates may have the plates individually wrapped in black paper, in the dark room or at night, and all the remaining work may be done in the light. A plate is taken from its wrapping into the lighted room and placed in the slide holder. After exposure, it is taken out into the light and placed in the developing bath, and the picture is then developed in the light, and may be fixed in the light. Of course during the changes the plate should be shielded from the light as much as is feasible, and the fixing bath may always be covered. But all of the operations may be carried on without any dark-room conveniences that may not be secured even in the open fields.

When weak hydrochinone baths are used, the picture, when developed in strong lamp light, or in sunlight, has at first a golden yellow color. When left in the lighted bath for an hour and a half, it slowly darkens to a nearly normal shade, as the details come out more sharply. If the exposure has been correctly made, there will be no trace of fog. With stronger baths, the picture comes out in the normal time, and has the normal shade.

If the pictures are too dense, the remedy is to reduce the strength of the sodium carbonate solution, or to increase the amount of hypo in the bath. Very fine results are obtained with the sodium carbonate solution at half the strength given in Cramer's formula.

When the plate has been sufficiently exposed, a negative of the object can usually be seen upon the plate before development. With long exposure this image is very distinct. It fades out in the bath, and the plate becomes clear. The shadows appear strongly but indistinctly at first, and of a pink color, and the high lights still appear white. The solution remains clear. Too much hypo will cause turbidity and a loss of detail.

When the plate is exposed in a printing frame under either a negative or a positive, an exposure of half a minute to diffuse daylight is ample, with an ordinary negative. The plate may be overexposed by placing it for a long time in direct sunlight, and it will then appear on development somewhat like an overexposed negative. This has not yet been tried with hypo in the bath.

Professor Nipher showed a preliminary diagram in which exposure and illumination of the developing bath were taken as co-ordinates. The zero condition was represented by a line, and the conditions for producing direct and reversed pictures were represented by areas.

He also exposed and developed, in a common bath, in the lighted audience room, negatives printed from negatives, and positives printed from positives.

The value of radio-active substances acting upon the developing plate in place of or in addition to light was referred to as a most promising field for study.

Professor Nipher stated that he had done no work with the plates of other makers, since he found on trial that one such plate did not give good results with the treatment that had succeeded with the Cramer plates.

Mr. H. J. Gerling, of St. Louis, was elected to active membership.

Three persons were proposed for active membership.

Reports of Officers for the Year 1900.

Submitted January 8, 1900.

The President addressed the Academy as follows: —

Members of the Academy: In rising to accept the honor which you have again conferred upon me in electing me President of the Academy, I would take the opportunity to make a few remarks upon the work which the Academy has attempted to do during the past year.

It is needless for me to say that the general policy of the Academy which has been followed for several years past has also been followed during the year which has just closed. No new departures have been attempted, partly because the policy which we had been following was thought to be a good one, and partly because we were restricted in our facilities and opportunities for attempting new work.

All of the meetings of the Academy which have been assigned by the Council at the beginning of the year have been held upon the dates appointed, to the number of sixteen. The record shows that the attendance at the meetings has been better than in any previous year. I think this fact is significant in showing that the Academy is gradually beginning to interest a larger constituency, and it is important that such means should be taken by the Council as to continually enlarge that constituency, because it is from those interested in the Academy's work that we must expect to derive our sustenance.

Papers and addresses of scientific interest have been presented at each meeting of the Academy. The value of these papers it is, of course, very difficult to estimate, but the estimation in which they have been held is indicated to some extent by the comments which have been made upon them in the scientific press throughout the world, and also by the attention which they have attracted not only in St. Louis but elsewhere in this country and in Europe. A number of the papers presented have been thought by the Council worthy of publication in the Transactions, and I am again happy to announce that the Council has been able to follow out the plan inaugurated a year or two ago, of publishing a volume during each year. During the past year we have published a volume of the Transactions, numbering approximately three hundred and fifty pages, illustrated with a large number of plates, and containing ten numbers. The present volume, which is the tenth of the Academy's publication, will contain, besides the usual matter, a classified table of the contents of all the ten volumes which have already been published, which will serve to make the contents of the earlier volumes more easily accessible.

We have before us many of the problems which were before us at this time last year. The Librarian has informed you of the increase in the library, which we consider one of our most valuable assets at present. The library now numbers 13,624 volumes and 9,869 pamphlets. It is housed, as you know, in the upper floor of this building: it should not be housed there. The necessity for a fire proof building in which the library can be preserved becomes year by year more imperative. It would be a disgrace to the city of St Louis if by any accident that library were to be destroyed. Yet we find it at present impossible to make other provision for the storing of the library, because of lack of funds. Any effort, therefore, which can be made on the part of members of the Academy to enlist public interest in securing a fire-proof home for the Academy and its collections should be encouraged. and should be put forth at every opportunity. Another thing which the library is in need of is a catalogue. At present the knowledge of the contents of the library is contained only in the head of the Librarian, so far as I am able to ascertain, and, while the books are reasonably accessible, it is impossible to ascertain what the library contains on any particular subject without going through a considerable amount of labor. Now. the making of a catalogue will involve considerable labor, and consequently considerable expense, and I desire to urge upon the Council the consideration of ways and means by which this can be accomplished, even if we do not find it feasible to move the library to a safer place.

We have, as you have heard, made an addition to the collections of the Academy, this year, which is quite exceptional. We have thought it best to purchase the Yandell collection of crinoids, corals, mollusks, crustacea and other fossil specimens. This collection, I may say, was made by Dr. Yandell, of Louisville, Kentucky, who was an associate of Dr. Shumard, whose name the St. Louis Academy always delights to honor as one of its early Presidents and one of its most enthusiastic workers. The collection consists of several thousand specimens, of which perhaps one third are crinoids. It is especially rich in crinoids of the Devonian age and many rare types contained in the collection are described in Volume I of the Transactions of The Academy of Science of St. Louis in an article by Yandell and Shumard, and others in the Contributions to the Geology of Kentucky, published somewhere about 1847; and I am informed by persons who are capable of judging of the scientific value of the collection that it is probably one of the best of its kind, if not the best, in this country. It is also an interesting fact, in connection with the acquisition of this collection, that the Shumard collection, to which this is complementary, is in the possession of Washington University, thus making both collections accessible in St. Louis to any student in that line of research. The acquisition of this collection again emphasizes the need of a fire-proof building.

I desire to state, for your information the terms on which the collection was secured. It was purchased from the widow of Dr. Yandell, for $1,000. Of this amount, a quarter, that is, $250, was paid as a cash payment, and this $250 has already been subscribed by members and friends of the Academy. Three notes were given, authorized by the Council and signed by the officers, payable respectively in one, two and three years, for $250 each. It is earnestly hoped that the members of the Academy will interest themselves in securing subscriptions during the year to enable the Academy to pay these notes as they mature, without encroaching on the current funds of the Academy, which are needed for current expenses, of which we have only too many.

I have very little more to say with reference to the actual work of the Academy. I do, however, wish to congratulate the Academy upon the quality and the quantity of the work which it has been doing during the past year, under great difficulties and with very limited means. It is very desirable that the membership of the Academy should be largely and speedily increased. The increase in membership during the past year has been considerable. You have heard from the report of the Treasurer that 59 new members have joined the Academy. The present membership is 286, an increase over the membership at this time last year of 33. I will call your attention again to the remarks which I made at the last annual meeting of the Academy, which you will find published at the end of the last volume of the Academy's Transactions, with reference to the persistence of the members in the Academy's list. We find by studying the record that, while new members join in considerable numbers, on the average they do not remain with the Academy a very long time; consequently, unless we have a continuous flow of new members, the supply is likely to be soon exhausted, and, since we are compelled to depend almost wholly upon the dues which members pay in order to meet our current expenses, it is easy to see that, unless effort is made to keep the membership up, it will not be possible to continue very long the work of publication of the Transactions on the scale on which it has been undertaken. On the other hand, I am happy to be able to say that we have more members of The Academy of Science of St. Louis to-day than ever before in its history, and I think that with the same effort that has been made that number will continually grow. I only wish to urge upon you the necessity of earnest and continuous effort in this direction.

The Treasurer reported as follows: —

RECEIPTS.

Balance from 1899	$2,239 13	
Interest on invested money	347 07	
Membership dues	1,565 00	
Invested capital returned	1,400 00	
		$5,551 20

EXPENDITURES.

Rent	$337 50	
Current expenses	230 46	
Publication of Transactions	1,053 05	
Reinvestment of capital	3,479 93	
Balance to 1901	450 26	
		$5,551 20

INVESTED FUND.

Invested on security	$6,500 00

The Librarian reported that during 1900 exchanges had been received from 274 societies, of which 17 were new; and three of the institutions formerly carried on the exchange list were reported as extinct. In all, 848 numbers were reported as having been added to the library, an increase of 103 as compared with the preceding year. It was reported that during the year the Transactions of the Academy had been distributed to 552 societies or institutions, chiefly by way of exchange or donation.

ON THE TEMPERATURE OF THE SUN AND ON THE RELATIVE AGES OF THE STARS AND NEBULAE.*

T. J. J. SEE.

PART FIRST.

ON THE GRAVITATIONAL THEORY OF THE SUN'S HEAT.

1. *The Theory of Helmholtz for the Condensation of a Sphere of Uniform Density.*

On the occasion of the Kant Commemoration at Königsberg, Feb. 7, 1854, Helmholtz delivered a popular address on the *Interaction of Natural Forces*, which contained the first application of the mechanical theory of heat to the radiation of the sun. In such a public discourse obviously nothing but the results of the calculations could be announced, as the mathematical methods involved are much too abstruse for a general audience; and hence in the *Populäre Vorträge* there are no indications of the processes by which the computations were made. This justly celebrated address was deemed worthy of translation and republication in the *Philosophical Magazine* for 1856, p. 516; and fortunately in this English edition the great physicist was induced to give the rigorous formulae used in deriving the numerical results.

The problem is: *To find the heat developed by the condensation of a homogeneous sphere under the influence of its own gravitation.*

The potential of a homogeneous sphere upon a unit mass at its surface is

$$V = \frac{4}{3}\pi\sigma\frac{R^3}{R} \tag{1}$$

* Presented in abstract to The Academy of Science of St. Louis, March 30, 1899.

The mass of a spherical shell of density σ and thickness dR is

$$4\pi\sigma R^2 dR.$$

The potential of the sphere upon the matter of the surrounding shell of thickness dR, is therefore

$$d\Upsilon = \frac{4}{3}\pi\sigma R^2 . 4\pi\sigma R^2 dR \qquad (2)$$

Now suppose we regard R as variable, and find the integral of the successive elements of the potential of the sphere upon itself, when the radius changes from 0 to R. This will give the potential of each succeeding sphere upon its surface, or in the limit the potential of the sphere upon itself.

$$\Upsilon = \frac{16\pi^2}{3}\int_0^R \sigma^2 R^4 dR. \qquad (3)$$

As the attraction of a homogeneous spherical shell with respect to points within is zero, we may disregard the action of any layer upon the inclosed sphere, and consider merely the action of the successive spheres upon their surfaces; the result will be the potential of the sphere upon itself, and correspond to the total energy given up by the particles in condensing from infinity. Accordingly when σ is constant, we have

$$\Upsilon = \frac{16}{3}\pi^2\sigma^2\int_0^R R^4 dR = \frac{3}{5}\left(\frac{4}{3}\pi\sigma R^3\right)\left(\frac{4}{3}\pi\sigma\frac{R^3}{R}\right) = \frac{3}{5}\frac{M^2}{R}. \quad (4)$$

Hence the theorem: *The potential of a homogeneous sphere upon itself is equal to three-fifths of the square of the mass divided by the radius.*

If masses are expressed in grammes instead of in astronomical units, equation (4) must be multiplied by the gravitation constant Γ, the value of which may be determined in terms of any special case of attraction. Thus let g be the acceleration due to gravitation, or the weight of a gramme, at the earth's surface, let m and r represent respectively the mass and radius of the earth ; then $g = \Gamma \frac{m}{r^2}$. The value of Γ from this equation in (4) gives

$$\Upsilon = \frac{3}{5}\,\frac{M^2}{R}\,\frac{r^2 g}{m}, \tag{5}$$

which is an equation of great importance.

Although the figures of the planets of the solar system and doubtless of the stars in general are probably spheroids of revolution, we may here treat them approximately as spheres. If we suppose the particles of the sun or of a planet to be scattered throughout immensity, and to condense gradually into a small globular mass such as we now observe, it is evident that the work of condensation for any particle of the globe will be equal to the potential of the corresponding concentric sphere upon a particle at its surface. Thus the total work of condensation is equal to the potential of the sphere upon itself. For any planet we have

$$\Upsilon' = \frac{3}{5}\,\frac{M'^2}{R'}\,\frac{r^2 g}{m} \tag{6}$$

Comparing (5) and (6) we get

$$\Upsilon : \Upsilon' = \frac{M^2}{R} : \frac{M'^2}{R'} \tag{7}$$

Therefore the potentials of two homogeneous spheres upon themselves are to each other as $\frac{M^2}{R}$ *to* $\frac{M'^2}{R'}$. Accordingly, in the solar system the potentials of the planets upon themselves are very small compared to that of the sun upon itself. Thus in the case of the largest planet, Jupiter,

$$M' = \frac{1}{1047.37} M,\ R' = \frac{R}{10}, \text{ and}$$

$$\Upsilon' = 10\left(\frac{1}{1047.37}\right)^2 \Upsilon = \frac{1}{109708.4}\,\Upsilon.$$

And hence we see that in condensing from a state of infinite expansion the planet Jupiter has developed less than $\frac{1}{1000000}$th part of the heat produced by the condensation of the sun. From this it is obvious that the sum of the potentials of all the other planets upon themselves is very much smaller than that of Jupiter alone; and as the potential of the sun upon itself is uncertain by at least twice the potential of Jupiter upon itself, we may regard the potential of the sun upon itself as furnishing sensibly all the energy developed by the solar nebula in condensing from a state of infinite expansion. Accordingly, having shown that (5) will give the total work of condensation of the solar nebula, we may now express the resulting energy in heat units.

To elevate the temperature of a mass M of specific heat ζ, θ degrees centigrade, we require an amount of heat $M\zeta\theta$.

We shall express the mechanical equivalent of the unit of heat by Ag, in which A is the altitude through which a kilogramme must fall, and g is the force of gravity. In French measure Ag will be 424 Kilogrammeters. Then the resulting heat developed by the falling mass will correspond to the work, and we shall have

$$W = M\zeta\theta\, Ag. \tag{8}$$

We may put Υ for W, and then for the condensation of the sun we shall have

$$\Upsilon = M\zeta\theta\, Ag = \frac{3}{5}\,\frac{M^2}{R}\,\frac{r^2 g}{m} \tag{9}$$

Accordingly,

$$\theta = \frac{3}{5}\,\frac{M}{R}\,\frac{r^2}{m}\,\frac{1}{A\zeta} \tag{10}$$

To determine θ numerically, we make use of the following values: —

$$\begin{aligned} M &= 330{,}000, \\ m &= 1, \\ A &= 424, && \text{(metres)} \\ r &= 6{,}378{,}190, && \text{"} \\ R &= 697{,}235{,}650, && \text{"} \\ \zeta &= 1 \text{ (water).} \end{aligned}$$

Then

$$\theta = 27{,}246{,}740^\circ \text{ C.} \tag{11}$$

Hence we conclude that in condensing from infinity to its present dimensions the total heat developed by a homogeneous sun would raise the temperature of an equal mass of water about 27 million degrees centigrade. As the mean distance of Neptune is equal to about 6570 of the present radii of the sun, we see by formula (10) that in condensing from infinity to the orbit of the outermost planet, only $\frac{1}{6570}$th part as much heat was produced as has been developed since.

According to the best available authorities the masses of the planets are as indicated in the following table: —

Name.	Mass in Units of the Sun's Mass.	Authority.
Mercury	$\frac{1}{7636440}$	Von Asten.
Venus	$\frac{1}{401847}$	Leverrier.
Earth	$\frac{1}{330000}$	Newcomb.
Mars	$\frac{1}{3,093,500}$	Hall.
Jupiter	$\frac{1}{1047.37}$	Hill and Newcomb.
Saturn	$\frac{1}{3501.6}$	Bessel.
Uranus	$\frac{1}{22800}$	Hill.
Neptune	$\frac{1}{19400}$	See.

If we add all these masses together we shall find the total to be $\frac{1}{745.77}$th that of the sun. The masses of the comets and asteroids are so small that we might neglect them altogether. For according to a determination recently made by Mr. Rossel of the Johns Hopkins University the combined masses of three hundred or more of the larger asteroids is less than one-eighth that of our moon. Taking therefore the nearest whole number we may assign the sun 746 times the mass of all the other bodies of the planetary system. Thus if we desire to find out the temperature to which a mass equal to the whole solar system would be raised we must multiply the value of θ in (11) by $\frac{746}{747}$, which will produce only a slight change.

If instead of supposing the particles of the sun to condense from infinite expansion we take a large primitive exterior radius R_0, the formula for the elevation of temperature becomes

$$\theta' = \frac{3}{5}\frac{M}{m}\frac{r^2}{A\zeta}\left(\frac{1}{R_1} - \frac{1}{R_0}\right),$$

where R_0 and R_1 are the successive radii to which the mass has shrunk. This may be put into the form

$$\theta' = \frac{3}{5}\frac{M}{m}\frac{r^2}{A\zeta R_1}\left\{1 - \frac{R_1}{R_0}\right\} \qquad (12)$$

For the case of a nebula filling the orbit of Neptune and then shrinking to the present dimensions of the sun, we note that $R_0 = 6570\,R$; and hence we may conclude that if the primitive nebula extended only to the limits of the planetary system the above value of θ in (11) would have to be diminished by about one six-thousandth part. Therefore we see that nearly all the heat of the sun has been developed since the primitive nebula attained the dimensions of the solar system. The following table shows the amount of heat developed by the solar nebula (assumed to be homogeneous) at different stages of its contraction.

Planetary orbit to which the nebula has shrunk.	Radius in units of the sun's radius.	Temperature θ to which aqueous globe of same mass as the sun would be raised by the heat.	Part of total energy developed by the homogeneous solar nebula.
Neptune..........	6570.	4,147.	1 ÷ 6570
Uranus..........	4200.	6,487.	1 ÷ 4200
Saturn..........	2089.	13,043.	1 ÷ 2089
Jupiter..........	1139.	23,923.	1 ÷ 1139
Ceres..........	606.	44,960.	1 ÷ 606
Mars..........	334.	81,577.	1 ÷ 334
Earth..........	219.	124,410.	1 ÷ 219
Venus..........	158.	172,440.	1 ÷ 158
Mercury..........	85.	320,550.	1 ÷ 85
50 Radii..........	50.	544,934.	1 ÷ 50
40 "	40.	681,168.	1 ÷ 40
30 "	30.	908,224.	1 ÷ 30
20 "	20.	1,362,336.	1 ÷ 20
10 "	10.	2,724,672.	1 ÷ 10
5 "	5.	5,449,344.	1 ÷ 5
2 "	2.	13,623,360.	1 ÷ 2
1 "	1.	27,246,720.	1 ÷ 1

The table shows clearly that the principal part of the sun's heat was developed at a late stage of its contraction. Thus the amount of heat developed before the nebula came within the orbit of Mercury is only $\frac{1}{85}$th part of the total produced up to the present time. We see by this example an emphatic indication that nebulae radiate very little heat compared to that given out in the stellar stage of evolution; and hence it is easy to infer the production of a vast amount of heat in the last stages of contraction. If in (11) we differentiate θ with respect to R we shall have

$$\frac{d\theta}{dR} = -\frac{3}{5}\frac{M}{R^2}\frac{r^2}{m}\frac{1}{A\varsigma}, \text{ or}$$

$$\frac{d\theta}{dR} = -\frac{C}{R^2} \qquad (13)$$

By this formula we see that when R is very small, $\frac{d\theta}{dR}$ becomes very large; and the production of heat for a given change of R becomes a maximum when R is a minimum. As no physical mass can have a radius infinitely small, it follows that the output of heat for a given change of R can never become infinite.

If we apply formula (12) we may determine the amount of heat generated by the sun in contracting one ten-thousandth part of its present radius; and we find $\theta' = 2725°$ C. Thus a contraction of $\frac{1}{10,000}$th part in the radius of the sun supposed homogeneous, or 69723 metres, would produce an amount of heat sufficient to elevate the temperature of a corresponding mass of water 2725° C.

Some sixty years ago Pouillet found by experiments on solar radiation that the amount of heat annually lost by the sun would raise the temperature of such a mass of water 1.25 degrees centigrade. On this basis a shrinkage of one ten-thousandth part of the radius would sustain the present radiation for 2180 years. More recent determinations of solar radiation, especially those made by Langley, increase the amount of heat by one-fourth or one-fifth, and hence it is probable that the above duration should be multiplied by $\frac{4}{5}$ or $\frac{5}{6}$. If in like manner we divide 27246740 by 1.5, which seems to be a fair modern estimate of the temperature through which an equal mass of water would be elevated by the heat annually lost by the sun, we shall obtain about eighteen million years as the past duration of the sun's heat, computed on the hypothesis of homogeneous density and uniform radiation.

It will of course be understood that the heterogeneity of the actual sun renders this result merely an approximation to the phenomenon of nature. The potential upon itself of a sphere whose density increases towards the center is greater than if the mass be homogeneous by an amount corresponding to the potential energy given up by the particles of a homogeneous sphere in falling towards the center to produce the heterogeneous one. Thus the past duration of the sun is really much greater than is indicated by the hypothesis of homogeneity, as will be shown in the next section.

Let us now consider the energy of the motions of the planets. The *vis viva* of motion of revolution about the sun of any body of mass m', is $\frac{1}{2}\,m'\,v'^2$, where v is the velocity; and hence if E_k denotes the kinetic energy of a planet we shall have $E_k = \frac{1}{2}\,m'v'^2$.

If E_p be the potential energy, and the system be supposed to be a conservative one, as if composed of rigid bodies revolving in empty space, we shall have a constant $C = E_p + E_k$. In the planetary system the orbits are of course somewhat eccentric. It is evident that for any planet E_k is a maximum at perihelion and a minimum at aphelion, while the potential energy is just the reverse at the two points. The general formula for the velocity of a planet * is

$$V'^2 = k^2\,(1 + m')\,\left\{\frac{2}{r'} - \frac{2}{2a'}\right\} \qquad (14)$$

where k is the Gaussian constant, r' the radius vector, and a' the semi-axis major of the orbit. From this formula we see that if $r' = 2a'$, the velocity is zero, and all of the energy of

* cf. *Watson's Theoretical Astronomy*, p. 49; or any work on Celestial Mechanics.

the planet becomes potential energy. Thus the velocity at any instant is equivalent to that which would be produced by letting the planet fall to its position from rest at a distance $2a'$.

Substituting this value of v', we have

$$E_k = \frac{1}{2} m'k^2 \,(1 + m')\left(\frac{2}{r'} - \frac{2}{2a'}\right) \tag{15}$$

In astronomical units k^2 expresses the mass of the sun and k^2m' the mass of the planet. Using M for k^2 in this formula we may write

$$E_k = Mm'\left(\frac{2}{r'} - \frac{2}{2a'}\right) + Mm'^2\left(\frac{2}{r'} - \frac{2}{2a'}\right) \tag{16}$$

Now suppose the planet at perihelion to touch the surface of the sun; then $r' = R$, and E_k will become a maximum. The second term of (16) is very small on account of the factor m'^2; and therefore may be disregarded. In the remaining term the part depending on $\frac{1}{a'}$ is small compared to that depending on $\frac{1}{R}$, and thus we have approximately

$$E_k = \frac{Mm'}{R} \tag{17}$$

Comparing this expression with (4) we see that

$$E_k : \Upsilon = 5m' : 3M. \tag{18}$$

But E_k is the *vis viva* of a single planet only, and hence we shall have

$$\sum_{i=1}^{i=i} \frac{E_{ki}}{\Upsilon} = \frac{5}{3M} \sum_{i=1}^{i=n} m_i = \frac{5}{3}\,\frac{1}{746}:$$

and thus for the solar system

$$\sum_{i=1}^{i=8} E_{ki} = \frac{1}{447.6}\,\Upsilon \tag{19}$$

We conclude therefore that if all the planets fell into the sun they could not maintain his heat for a great length of time, since $\sum_{i=1}^{i=8} E_{ki}$ is small compared to Y. We may observe that by the previous suppositions E_k has been made to assume very nearly the value of C, as the neglected value of E_p is very small.

But in order to estimate the total kinetic energy we should take account of the rotations of the sun and planets and of the orbital motions of the satellites.

The energy of rotation of the satellites and of their orbital motions is relatively insensible, and we may also disregard the rotations of the planets; but an accurate estimate of the energies of the planetary system would require us to consider the energy of the sun's rotation. The moment of inertia of the sun depends upon the law of density, and unfortunately this can be inferred only approximately from certain hypotheses resulting from the theory of gases. Accordingly, it does not seem worth while to pursue further the subject of the energy of solar rotation.

We have seen that a contraction of 69723 metres in the sun's radius, the mass being supposed of homogeneous density, would maintain the observed radiation for 2180 years, or that an annual shrinkage of 35 metres per year would account for the observed output of light and heat.* Such a rate of contraction would affect the diameter of the sun less than a tenth of a second of arc in a thousand years, and would be wholly inappreciable during the period covered by exact observations. The fact that ancient and modern eclipses are sensibly of the same duration, taken in conjunction with

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* Ritter has computed this annual shrinkage on the supposition that the mass is heterogeneous and in convective equilibrium; and finds a value of about 90 metres. If, therefore, the density follows the laws treated in the next section, the shrinkage in the sun's diameter would be less than six-tenths of a second of arc since the days of Hipparchus. Were even the most refined measures available for the whole of this period, there would still be no hope of confirming the shrinkage by observations made within historical time.

the substantial constancy of the moon's mean distance, assures us that no considerable alteration in the diameter of the sun's globe has occurred within historical time. The essential constancy of solar radiation for the last two thousand years is well established by the observed conformity of the modern distribution of plants and animals with those recorded by Pliny and Theophrastus. It seems reasonable to assume that no cause but gravitational shrinkage as explained by Helmholtz, would be adequate to secure this perfect uniformity of light and heat for so great a period of time; and hence we need not discuss the other hypotheses which have been proposed to account for solar radiation, and which are now generally abandoned by astronomers.

2. *An Extension of Helmholtz's Theory to the Case of a Heterogeneous Sphere made up of Layers of Uniform Density, with Considerations respecting the Age of the Sun.*

We have seen that when the sun's globe is taken to have a uniform density, the total available energy supply could not maintain radiation at its present rate for more than some 18 millions of years. Though the actual radiation of the sun has undoubtedly been more or less variable, we shall for the sake of measurement consider it to have gone on uniformly at its present rate, and investigate the past duration of the sun's heat on the supposition that the density of the mass increases towards the center in accordance with the curves found by our countryman Lane, just thirty years ago, from the hypothesis of a gaseous mass in convective equilibrium. As a careful examination of the theory of Lane has disclosed no appreciable defects, it will be permissible to adopt the curves which he has given in the *American Journal of Science* for July,* 1870. These curves are reproduced in the accompanying plate.

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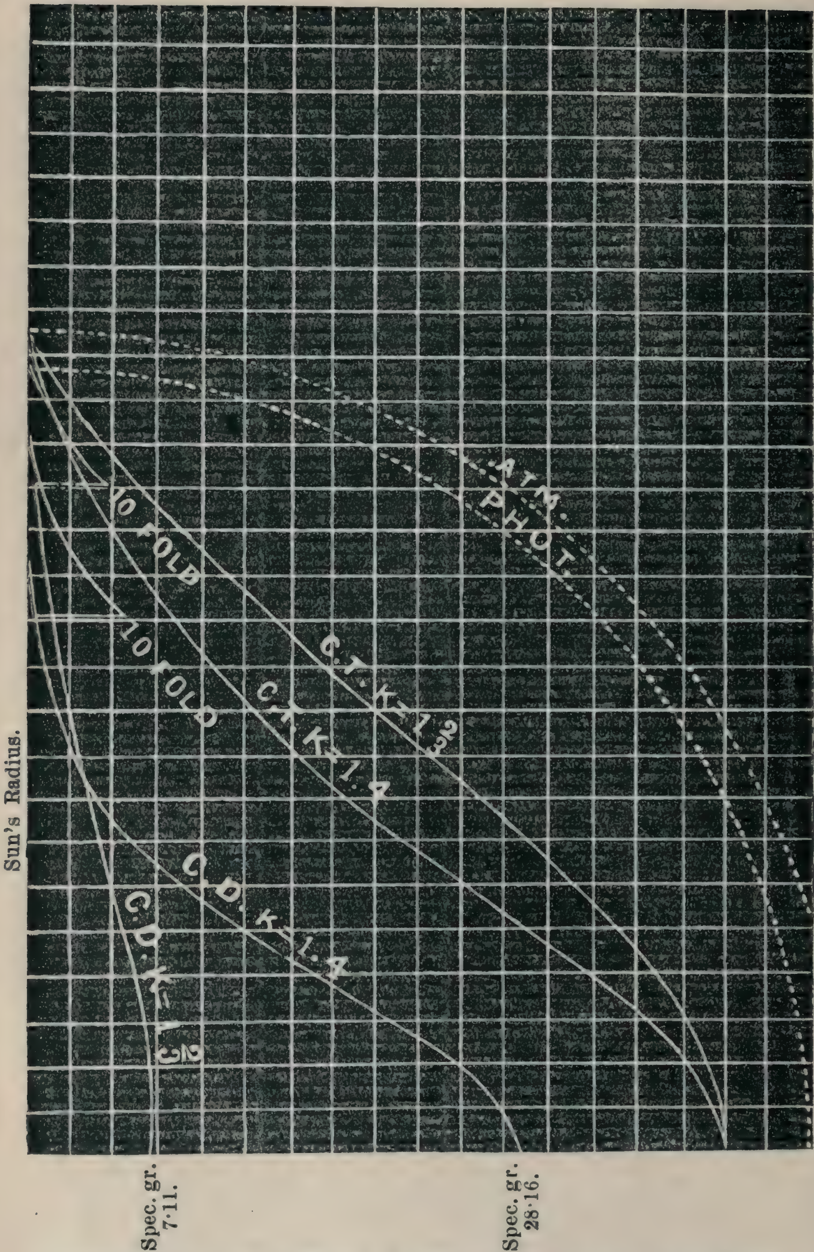
* *On the Theoretical Temperature of the Sun on the hypothesis of a gaseous mass maintaining its volume by internal heat, and depending on the laws of gases as known to terrestrial experiment,* by J. Homer Lane, of Washington, D. C. Read before the National Academy of Sciences, Apr. 16, 1869.



Explanation. — Atm., Assumed theoretic upper limit of atmosphere; Phot., Photosphere; C.T.K. = $1\frac{2}{3}$, Arbitrary Curve of temperature for $k = 1\frac{2}{3}$; C.T.K. = 1·4, Arbitrary Curve of temperature for $k = 1{\cdot}4$; C.D.K. = 1 4, Absolute Curve of density for $k = 1{\cdot}4$; C.D.K. = $1\frac{2}{3}$, Absolute density for $k = 1\frac{2}{3}$.

Lord Kelvin has computed these curves by a process different from that employed by Lane, and finds the density of the center of the sun about 32 times that of water. This result is based on the supposition that $k = 1.4$, as in common air, and most terrestrial gases. The rise in temperature near the center of the sun is quite as remarkable as the increase in density. If all the radiation comes from the photosphere, which Lane assumes to have a depth equal to one twenty-third part of the radius, the central temperature would be about 32 times that of the radiating layer; and if the effective temperature of the photosphere be taken at 8000° C. (as found experimentally by Wilson and Gray, *Phil. Trans.*, 1894), we shall be led to conclude that the central temperature is approximately 256000°C. Though a temperature of a quarter of a million degrees at the center of the sun is not improbable, we find it very difficult to appreciate its physical significance.

We shall now investigate the effects of an increase of density towards the center on the potential of the sphere upon itself. The surrounding shell is supposed to have the density λ, and hence the element of the potential is

$$dV = \frac{4}{3}\pi\sigma\ \frac{R^3}{R}\cdot 4\pi\lambda R^2 dR \qquad (20)$$

The density of a gaseous heavenly body which has attained a state of bodily equilibrium undoubtedly increases rapidly towards the center, and in general is a function of the radius. It thus happens that the bodies of gaseous stars and planets are made up of successive layers of uniform density. And since a spherical shell of uniform density exercises no attraction upon the particles within, the determination of the potential upon itself of such a heterogeneous sphere requires us to consider merely the action of each successive sphere upon its surface layer. If therefore we integrate equation (20) we shall find the amount of energy given up by the particles of a heterogeneous sphere in falling together from infinite expansion.

$$V = \frac{16\pi^2}{3}\int_0^R \sigma\lambda R^4 dR \qquad (21)$$

In the general case we have $\sigma = \Psi(R)$, $\lambda = \varphi(R)$, but as the forms of these functions are very complicated it is not easy to evaluate this integral except by some convenient process of mechanical quadrature. In his paper on the *Theoretical Temperature of the Sun*, Lane has developed λ in a converging series which enable us to find its numerical value for any argument with moderate facility. It is evident that at the center of the sun $\lambda_0 = \sigma_0$, and at the surface $\lambda_i = 0$.

Now suppose we express the density of the shell in units of the mean density of the sun, which is about 1.4 that of water, and from a table of λ_i in which R_i is the argument. Then Lane's work shows that λ_i will vary from $\lambda_0 = 20.06$, at the center, to $\lambda_i = 0$, at the theoretical upper limit of the solar atmosphere. On the same basis σ_i will vary from 20.06 to 1. The function $\sigma_i\lambda_i$ is therefore finite and continuous from $R = 0$, to $R = R_i$, at the surface of the sun. If the sun's radius be divided into i equal parts, the functions σ_i may be computed by the formula:

$$\sigma_i = \frac{o_0\lambda_0 + o_1\lambda_1 + o_2\lambda_2 + \ldots + o_i\lambda_i}{V_i} \qquad (22)$$

where o_0, o_1 o_2, . . o_i are the volumes of the central nucleus, and of the successive shells by which it is surrounded; λ_i being their several densities and V_i the volumes of the corresponding enclosing spheres. In the case of the sun it was deemed sufficient to divide the radius into forty equal parts; the following table gives the values of these several functions as determined by computation.

R_i	θ_i	λ_i	$\theta_i \lambda_i$	σ_i	$\log \sigma_i \lambda_i$	$\log (R_i^5 - R_{i-1}^5)$	$\Upsilon \chi \frac{15}{16\pi^2}$
0.25	0.0156	20.06	0.3129	20.06	2.604562	$\bar{4}$.989700	0.4
0.50	0.1094	19.80	2.1661	19.83	2.594032	$\bar{2}$.481062	11.9
0.75	0.297	19.32	5.7380	19.47	2.575408	$\bar{1}$.313981	77.5
1.00	0.578	18.52	10.7046	18.92	2.544399	$\bar{1}$.882351	267.1
1.25	0.953	17.62	16.7917	18.29	2.508134	0.312126	661.1
1.50	1.422	16.47	23.4203	17.52	2.460254	0.657245	1310.7
1.75	1.984	15.20	30.1568	16.66	2.403565	0.945437	2233.6
2.00	2.441	13.88	33.8811	15.40	2.329809	1.192760	3330.9
2.25	3.390	12.45	42.2055	14.52	2.257120	1.409347	4639.5
2.50	4.235	10.95	46.3732	13.55	2.171417	1.601961	5934.4
2.75	5.171	9.60	49.6416	12.57	2.081583	1.775397	7194.2
3.00	6.204	8.40	52.1136	11.61	1.989160	1.932727	8354.0
3.25	7.328	7.33	53.7142	10.70	1.894380	2.077695	9377.2
3.50	8.547	6.42	54.8717	9.85	1.800737	2.211198	10278.6
3.75	9.859	5.56	54.8160	9.05	1.701418	2.335170	10870.0
4.00	11.266	4.77	53.7388	8.28	1.597143	2.440903	10915.5
4.25	12.765	4.05	51.6982	7.59	1.487472	2.559404	11139.8
4.50	14.360	3.40	48.8240	6.93	1.371986	2.661540	10802.5
4.75	16.056	2.82	45.2779	6.31	1.250405	2.759991	10195.2
5.00	17.839	2.33	41.5649	5.75	1.126577	2.849372	9461.3
5.25	19.703	1.93	37.8298	5.22	1.001264	2.936195	8658.6
5.50	21.672	1.56	33.8083	4.75	0.869472	3.018907	7733.5
5.75	23.734	1.28	30.3795	4.31	0.742036	3.097826	6916.1
6.00	25.891	1.04	27.9666	3.92	0.610973	3.173325	6085.5
6.25	28.140	0.84	23.6376	3.57	0.476973	3.245701	5280.5
6.50	30.485	0.68	20.7298	3.25	0.344310	3.315155	4565.3
6.75	32.920	0.56	18.4352	2.96	0.219701	3.381978	3996.5
7.00	35.455	0.45	15.9548	2.70	0.084883	3.446281	3397.5
7.25	38.078	0.35	13.3273	2.47	9.936220	3.508318	2783.2
7.50	40.797	0.27	11.0152	2.25	9.784404	3.568199	2252.2
7.75	44.609	0.21	9.3679	2.06	9.636795	3.626120	1832.0
8.00	46.516	0.16	7.4426	1.89	9.480683	3.682123	1454.8
8.25	49.515	0.13	6.4370	1.73	9.353294	3.736410	1229.4
8.50	52.610	0.10	5.2610	1.59	9.202794	3.789044	981.4
8.75	55.796	0.08	4.4637	1.47	9.070091	3.840124	813.3
9.00	59.079	0.06	3.5447	1.35	8.910009	3.889776	630.6
9.25	62.453	0.046	2.8728	1.25	8.760181	3.937998	499.1
9.50	65.922	0.033	2.1754	1.16	8.582145	3.984956	369.1
9.75	69.484	0.020	1.3897	1.07	8.331424	4.030661	230.2
10.00	73.141	0.008	0.5851	1.00	7.900754	4.075183	94.6
							$\Sigma = 176868.$

The potential of the solar sphere upon itself * is given by

$$\frac{16\pi^2}{3}\int_0^R \sigma\lambda R^4 dR = \frac{16\pi^2}{3}\sum_{i=0}^{i=i}\sigma_i\lambda_i\int_{R_{i-1}}^{R_i} R^4 dR$$

$$= \frac{16\pi^2}{15}\Big\{\sigma_0\lambda_0 R_0^5 + \sigma_1\lambda_1(R_1^5 - R_0^5) + \sigma_2\lambda_2(R_2^5 - R_1^5)$$

$$+ \ldots\ldots\ldots\ldots\ldots\ldots + \sigma_i\lambda_i(R^5_{i+1} - R^5_i)\Big\} \quad (23)$$

* Cf. *Astronomische Nachrichten*, No. 3586.

When $i = \infty$ this approximate expression becomes rigorously exact. In the simple case of homogeneity considered by Helmholtz, namely,

$$r = \int_0^R \frac{4}{3}\pi\sigma \frac{R^3}{R} \cdot 4\pi\sigma R^2 dR = \frac{3}{5}\frac{M^2}{R},$$

we have shown that all the energy developed by the falling together of the particles of the sun would raise the temperature of an aqueous globe of the same mass 27,246,720° C. The above integration for the heterogeneous sun shows that it has given up energy greater than that of a corresponding homogeneous sphere in the ratio of 176,868 to 100,000. As the development of energy found by Helmholtz would maintain the observed radiation for about eighteen million years, it follows that if we suppose the sphere investigated by him to have afterwards passed into the actual sun by most of the particles falling towards the center, the energy thereby developed would have maintained the observed radiation through an additional period of 13,936,240 years. This considerable augmentation of the sun's past longevity diminishes correspondingly the duration which may be set for his future supply of light and heat.

Shrinkage of the sun's radius to one-half and one-third its present value respectively, would, by the theory of Helmholtz, double and treble the amount of heat produced in condensation. If the actual sun were homogeneous and had already lost but eighteen million years of energy measured by the present standard output, it would follow that when the diameter has shrunk to one-half and one-third its present value, the total resulting output would last thirty-six and fifty-four million years respectively.

Those who have studied the physics of the sun incline to the belief that contraction can hardly continue unchecked *

* Molecular forces may resist compression, yet they do not diminish the total energy given up by the condensation of the mass. If the resisting forces become so strong that the body no longer behaves as a perfect gas, the shrinkage might go on so slowly that cooling would take place.

by molecular forces after the radius has shrunk to one-half its present value, which would give an average density of 11.2, and certainly not after the radius has shrunk to one-third of its present value, which would give a mean density of 37.8. From these considerations it seems certain that if the total available supply of energy exceeds the output of thirty-six million years, measured by the present standard, it must necessarily fall short of one extending over fifty-four million years.

The calculation of an energy supply furnishing uniform radiation at the present rate for thirty-six million years, seems to the author a just estimate of the total available energy of the sun.

If this be adopted, *it will follow from the above calculation that eight-ninths of the sun's available energy has already been expended.* This conclusion is based upon the assumptions —

(1.) That the sun's mass is gaseous and the density follows the curve found by Lane.

(2.) That shrinkage will essentially cease when the globe has attained the average density of 11.2.

(3.) That the ratio of the specific heat of the solar gas under constant pressure to that of the gas under constant volume is 1.4, as in common air and most terrestrial gases; and moreover that the average specific heat of the sun's mass is not enormously great, so that the latent heat of cooling would become a great source of energy after shrinkage has entirely ceased.

The justice of all these hypotheses may not be perfectly obvious, yet it is difficult to see how the first two can be called into question.

The matter composing the body of the sun is much above the critical temperatures of all known substances and thus is necessarily in a gaseous state, though in the nucleus it may be so far condensed under the enormous pressure to which it is subjected as to act like a solid or fluid of great viscosity. On the other hand even though the central density be 28 times that of water, while the photosphere is rarer than the terrestrial atmosphere, it is hardly conceivable that appreciable shrinkage can go on after the average density of the globe has increased to eight times its present value. For the resistances due to molecular repulsive forces must tend to overcome gravitational pressure, and at length render further contraction impossible. If this state be not completely realized when the sun's radius has shrunk to one-half its present value, it must yet be so fully attained in the greater part of the body of the sun that what further shrinkage is possible in the external layers will produce little available energy for maintaining the sun's heat. As to the specific heat of the sun we can only say that, with one unimportant exception, water has the greatest specific heat of all known terrestrial substances; and it is not probable that the average specific heats of the dense gases comprising the body of the sun can be enormously greater than those of the corresponding gases found upon our earth. Wherefore it is not easy to imagine how our sun can long maintain its radiation after shrinkage has entirely ceased.

Hitherto we have assumed that $k = 1.4$, as in common air and most terrestrial gases. Though this value is based upon the study of many gases under widely-varying conditions, there are theoretical reasons for supposing a larger value to correspond more closely with the state of things existing in the body of the sun, where it is not improbable that many of the gases, disassociated by great heat, behave as if monatomic. In such monatomic gases where the energy is applied in the form of translational kinetic energy, and none goes to work done upon the internal structure of the molecules themselves it is known from Clausius' theory of the gases that k attains a maximum value 1.66. In one well-known case this has been experimentally confirmed by Professor Kundt, who found for the vapor of Mercury, which on chemical ground is known to be monatomic, the experimental value 1.66. In contrast to this large value of k, some substances of complex molecular structure give experimentally a very small value. Thus in oil-of-turpentine vapor k is only 1.03. But it is not probable that substances of such elaborate structure exist in the body of the sun, where the intense heat necessarily renders complex molecular structure difficult of formation. The curve of density for $k = 1.66$, has been drawn by Lane, and the corresponding integration for the potential of such a monatomic sun upon itself is given in the following table: —

R_i	θ_i	λ_i	$\theta_i \lambda_i$	σ_i	$\log \sigma_i \lambda_i$	$\log (R_i^5 - R_{i-1}^5)$	$\Upsilon x \frac{15}{16\pi^2}$
0.25	0.0156	5.08	0.0792	5.08	1.411464	$\bar{4}.989700$	0.0
0.50	0.1094	5.07	0.5547	5.07	1.410119	$\bar{2}.481062$	0.8
0.75	0.297	5.06	1.5028	5.06	1.408582	$\bar{1}.313981$	5.3
1.00	0.578	5.04	2.9131	5.05	1.405704	$\bar{1}.882351$	19.4
1.25	0.953	5.00	4.7650	5.03	1.400149	0.312126	51.6
1.50	1.422	4.94	7.0247	5.00	1.391782	0.657245	112.0
1.75	1.984	4.85	9.6224	4.94	1.379279	0.945437	211.2
2.00	2.441	4.72	11.5215	4.75	1.350446	1.192760	349.3
2.25	3.390	4.56	15.4584	4.69	1.330322	1.409347	549.1
2.50	4.235	4.37	18.5070	4.61	1.303685	1.601961	804.7
2.75	5.171	4.16	21.5114	4.50	1.271740	1.775397	1114.6
3.00	6.204	3.93	24.3817	4.36	1.234329	1.932727	1469.1
3.25	7.328	3.69	27.0403	4.22	1.192392	2.077695	1862.5
3.50	8.547	3.46	29.5726	4.07	1.148555	2.211198	2289.6
3.75	9.859	3.25	32.0418	3.92	1.104705	2.335170	2753.4
4.00	11.266	3.05	34.3613	3.76	1.059881	2.440903	3168.0
4.25	12.765	2.86	36.5079	3.61	1.014256	2.559404	3746.8
4.50	14.360	2.67	38.3412	3.46	0.966157	2.661540	4243.2
4.75	16.056	2.49	39.9794	3.31	0.917189	2.757991	4733.5
5.00	17.839	2.31	41.2081	3.17	0.865377	2.849372	5185.0
5.25	19.703	2.14	42.1644	3.04	0.812459	2.936195	5606.0
5.50	21.672	1.98	42.9106	2.89	0.758586	3.018907	5991.0
5.75	23.734	1.82	43.1959	2.76	0.701364	3.097826	6297.8
6.00	25.891	1.67	43.2380	2.63	0.642919	3.173325	6550.0
6.25	28.140	1.53	43.0545	2.50	0.583418	3.245701	6747.1
6.50	30.485	1.39	42.3742	2.38	0.519741	3.315155	6837.5
6.75	32.920	1.26	41.4792	2.26	0.454640	3.381978	6864.6
7.00	35.455	1.14	40.4187	2.14	0.388329	3.446281	6833.0
7.25	38.078	1.02	38.8396	2.03	0.316647	3.508318	6682.9
7.50	40.797	0.91	37.1253	1.92	0.243250	3.568199	6478.1
7.75	44.609	0.79	35.2411	1.82	0.157573	3.626120	6077.1
8.00	46.516	0.69	32.0960	1.72	0.073584	3.682123	5697.8
8.25	49.515	0.58	28.7187	1.62	9.972034	3.736410	5110.3
8.50	52.610	0.47	24.7267	1.52	9.853480	3.789044	4390.6
8.75	55.796	0.37	20.6445	1.42	9.721326	3.840124	3643.0
9.00	59.079	0.27	15.9518	1.33	9.554993	3.889776	2784.6
9.25	62.453	0.19	11.8661	1.24	9.371971	3.937998	2041.6
9.50	65.922	0.10	6.5922	1.15	9.061381	3.984956	1112.6
9.75	69.922	0.04	2.7794	1.07	8.630818	4.030661	458.6
10.00	73.141	0.01	0.7314	1.00	7.996092	4.075187	117.8

$\Sigma = 128990.$

It will be seen that the density at the center is very much smaller than in the case where $k = 1.4$, and of course the potential of the whole mass upon itself is correspondingly less exhausted. Thus the monatomic sun occupies a mean place between the Helmholtz homogeneous sun and the heterogeneous one already treated, in which $k = 1.4$. It appears that the relative ages of the three suns, or the periods of time during which they would furnish heat at the present rate, are in the ratio of the numbers: —

100000:	128990:	176868.
(18,000,000):	(23,218,200):	(31,836,240).

On the supposition that $k = 1.66$, the sun could have supplied light and heat at his present rate for over 23 million years.

As this represents a less exhausted condition than that of the heterogeneous sun first treated, it is clear that it has a greater future duration. Thus the futures of the several suns are as follows: —

(Homogeneous)	(Heterogeneous)	(Heterogeneous)
18,000,000:	$k = 1.66$	$k = 1.4$
	12,781,800:	4,163,760.

If we imagine that the density follows different laws according to the temperatures in different parts of the sun, that near the center agreeing approximately with the curve for $k = 1.66$, that near the surface conforming more nearly to the curve for $k = 1.4$, we shall be led to conclude that the future duration of the activity of the sun lies between four and twelve million years. In no case can the available energy furnish heat for a period exceeding twelve, while it probably will not fall short of four, million years.

It thus appears that the sun may have radiated for thirty-two millions of years; but under no hypothesis of uniform radiation can the age of the sun exceed some fifty millions of years.

These conclusions necessarily curtail in a very marked degree the periods hitherto assigned by geologists to the formation of the earth. Even if we suppose that the output of solar energy in early ages was enormously less than that now given out, and the period of time required for the expenditure of the total amount correspondingly increased, we shall still find it very difficult to imagine such a reduction in the output as will give to the earth a Geological History approximating 500,000,000 years. Indeed it is hardly conceivable that the period in question can surpass one-tenth of this figure, 50,-000,000 years; and a shorter period for terrestrial Geological History is to be anticipated. Since eight-ninths of the available energy of the sun is probably already exhausted, and our future supply must be based upon the remaining ninth, together with the latent heat of cooling, it seems fairly certain that the future of the sun's activity will be limited to a few million years. Thus it is not likely that life such as now exists upon our globe can be maintained by solar radiation after the lapse of three million years.

PART SECOND.

ON THE THEORETICAL DISTRIBUTION OF DENSITY AND TEMPERATURE FOR A GASEOUS SUN IN CONVECTIVE EQUILIBRIUM AND ON THE FUNDAMENTAL LAW OF TEMPERATURE FOR GASEOUS CELESTIAL BODIES.

The great pressure and temperature existing in the body of the Sun naturally suggest to us interesting questions regarding the physical condition and behavior of the matter of which it is composed. As all experiments upon the earth are conducted under conditions limited by the comparatively small pressure and low temperature at our command, it is not easy to infer from our experimental knowledge, obtained under very restricted conditions, just how any kind of matter would behave under the extreme conditions existing in the Sun. Yet it is found that all bodies, however hard, and whether of homogeneous structure, or made up of heterogeneous granulations embedded in a matrix, under great pressure tend to behave like fluids of great viscosity; and that with high temperature all bodies become either liquid or gaseous. It seems probable that the whole mass of the Sun is still gaseous; for if any portion be liquid or quasi-solid like the lava which issues from our volcanoes, it can only be that part which is near the Sun's center. If the central nucleus has ceased to be gaseous, it must be on account of the immense pressure to which it is subjected. Its high temperature will tend to preserve the gaseous state, but in the condensation of a mass like the Sun, a time must at length arrive when the influence of pressure will become predominant. Liquids will then begin to form, though they cannot solidify while the temperature is still very high.

Accordingly, assuming in line with the best available evidence that the body of the Sun is gaseous throughout, we shall now treat of the theory of convective equilibrium, and finally consider a very remarkable law of temperature, which applies to all gaseous celestial bodies, and apparently throws a new light on the processes by which the material universe has reached its present condition. We have elsewhere * discussed the history of the discovery of this law, and as nothing has since come to light to alter the statements then submitted, we content ourselves with observing that considerable additional credit should be given to Ritter, with the contents of whose researches the author was not acquainted at the time of composing the former paper. Ritter appears to have been the first investigator to arrive at the law treated in the concluding part of this paper, but it received so little attention from astronomers and other men of science that when the present writer found the law independently and made it known in the most learned circles, apparently no astronomer in this country was acquainted with Ritter's work. The importance of his researches will be admitted by all who have read his papers, but as some of his conclusions are contradicted by well-established phenomena of the heavens, it is safe to assume that a very cautious sifting of his results must be effected before the truth can be arrived at. As the law of temperature announced in *Astronomische Nachrichten*, No. 3585, has an important bearing on astro-physical theories, and yet to some minds presents difficulties which are greater than could have been anticipated, and on that account has been extensively discussed by astronomers, some denying the existence of such a physical law, others alleging that it was known

* Astronomical Journal, No. 455.

already, "though of course not in the shape of a formula introducing the idea and symbol of absolute temperature," it seems proper to offer, at this time, a connected view of the whole question. How far the author had been anticipated in the discovery of this law, and how he became acquainted with Ritter's work after writing the article in A. N. 3585, has been sufficiently set forth in the *Astronomical Journal*, No. 455. But it should be added here that at the time of composing that article, the writer was not aware of the existence of Ritter's earlier paper in *Wiedemann's Annalen* for 1878, s. 543,* in which he reached a formula and a number of conclusions essentially identical with those recently published. The scientific public will be able to judge how far these results of Ritter were known among astro-physicists, and what influence, if any, they had already exercised upon astronomical thought. In the present paper, written since May 1, 1899, it is to be understood that the author has availed himself freely of the works of Ritter † as well as of those of Lane ‡ and Lord Kelvin.¶

3. *On the convective equilibrium of a gaseous mass.*

Gaseous stars are continually losing heat by radiation, and contracting in consequence of the loss of heat, thereby growing denser and hotter. In stars of mature age the radiation is chiefly from the surface layers, and as these exposed portions soon cool off, it is evident that the continuity of the energy supply is maintained by the circulation of the mass in a state of convective equilibrium. Accordingly, we must explain the nature of the circulation and adiabatic contraction which sustains the steady light and heat of the stars.

A mass of gas changes adiabatically when it neither gains nor loses heat from contact with its surroundings, but expands and contracts in such a way as to adjust itself to the conditions which envelop it.

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* Professor Nipher first called attention to this paper, in one of the important contributions which he recently submitted to the Academy on this subject, *Transactions*, Vol. IX, No. 4.

† Wiedemann's Annalen, 1878 to 1882.

‡ American Journal of Science, July, 1870.

¶ Philosophical Magazine, 1887, p. 287.

By the law of Mariotte, the volume and pressure of any mass of gas are defined by the equation,

$$PV = NT \tag{24}$$

where N is a constant, and T is a fixed absolute temperature.

By the law of Gay Lussac, the volume of the same mass of gas under constant pressure is proportional to the absolute temperature, and defined by the equation

$$PV = NT \tag{25}$$

We shall assume that these laws, derived from terrestrial experiments on many single and compound gases under varied conditions, hold true also in the body of the Sun. A quantity of heat dQ applied to any element of the Sun's mass will do external work by expanding the volume (under constant pressure) and internal work against resisting molecular forces. Suppose A to be a constant, and let Φ and Ψ be unknown functions of the volume and internal pressure respectively. Then we shall evidently have the differential equation,

$$dQ = A\,(\Phi dP + \Psi d\,V) \tag{26}$$

If now we apply the heat to a unit volume of the gas under constant pressure, we shall have

$$dQ = A\Psi d\,V = \zeta_p dT \tag{27}$$

where ζ_p is the specific heat of the gas. Thus, under constant pressure,

$$\Psi = \frac{\zeta_p dT}{Ad\,V} \tag{28}$$

By the law of Gay Lussac in (25) we have $\dfrac{dT}{dV} = \dfrac{P}{N}$, and hence

$$\Psi = \frac{\zeta_p}{A}\frac{P}{N} \tag{29}$$

If now we suppose V constant, and apply the heat dQ to the gas under constant volume, we shall have

$$dQ = A\Phi dP = \zeta_v dT \tag{30}$$

where ζ_v is the specific heat under constant volume.

Since by (24) $\frac{dT}{dP} = \frac{V}{N}$, we have

$$\Phi = \frac{\zeta_v}{A} \frac{dT}{dP} = \frac{\zeta_v V}{AN}; \tag{31}$$

and thus (26) becomes

$$dQ = \frac{\zeta_v}{N} \left\{ VdP + \frac{\zeta_p}{\zeta_v} PdV \right\} \tag{32}$$

It is found by experiment that the ratio $k = \frac{\zeta_p}{\zeta_v} = 1.4$, in common air and most terrestrial gases; but in monatomic gases the value rises to 1.66, and in gases of very complex molecular structure falls to 1.03, as in vapor of oil-of-turpentine. Now suppose that the element of solar gas expands or contracts adiabatically, so that no heat is gained or lost by it; then $dQ = 0$, and (32) becomes

$$\frac{dP}{P} + k\frac{dV}{V} = 0 \tag{33}$$

which is the differential equation for the pressure and volume of an element of the Sun's mass in convective equilibrium. Integrating this equation for the changes undergone by the element in passing from the states P_1, V_1, to P, V, we have

$$\int_{P_1}^{P} \frac{dP}{P} + \int_{V_1}^{V} k\frac{dV}{V} = 0, \tag{34}$$

Equation (34) thus gives

$$\log P + k \log V = \log P_1 + k \log V_1, \text{ or}$$

$$PV^k = P_1 V_1^k \tag{35}$$

But since $\frac{V}{V_1} = \frac{\sigma_1}{\sigma}$, we may write,

$$P = P_1 \left(\frac{\sigma}{\sigma_1}\right)^k \tag{36}$$

With unit mass $\frac{P}{N}=\frac{T}{V}, =\frac{P_1}{N}=\frac{T_1}{V_1}$, and we have

$$T=T_1\left(\frac{\sigma}{\sigma_1}\right)^{k-1}$$

If now the density of the Sun at the point σ_1 be taken as unity, T_1 being the temperature of this point, we shall have the important equation

$$T=T_1\sigma^{k-1}, \tag{37}$$

by which the law of temperature can be determined as soon as the law of density is known.

4. *Determination of the law of density.* If we denote by m the mass included in the sphere of variable radius r, and by M the total mass included in the sphere of radius R, and by a the ratio of acceleration of gravity at the distances r and R from the center respectively, we shall have

$$a=\frac{mR^2}{r^2M} \tag{38}$$

Differentiating this equation with respect to r, we get

$$\frac{da}{dr}=\frac{R^2}{Mr^2}\frac{dm}{dr}-\frac{2mR^2}{Mr^3}, \text{ or}$$

$$\frac{da}{dr}=\frac{R^2}{Mr^2}\ \frac{dm}{dr}-\frac{2a}{r} \tag{39}$$

If now we designate the mean density of the sphere of radius R by $\bar{\sigma}$ we shall have

$$M=\frac{4}{3}\pi\bar{\sigma}R^3 \tag{40}$$

The element of mass between the two sphere surfaces r and $r+dr$ is given by

$$dm=\pi\sigma r^2dr \tag{41}$$

Then by (40)

$$\frac{dm}{dr}=\frac{3M\sigma r^2}{R^3\bar{\sigma}} \tag{42}$$

By means of this equation (39) takes the form

$$\frac{da}{dr} + \frac{2a}{r} - \frac{3\sigma}{R\bar{\sigma}} = 0 \tag{43}$$

A well-known theorem in the Kinetic theory of gases states that the internal heat of any element in convective equilibrium is equivalent to the mechanical energy required to raise the element to the limits of the atmosphere; for the adiabatic compression of the element from infinite expansion would develop this amount of heat; or an equivalent work would be done by the particles if the mass were allowed to expand indefinitely, as happens when the element circulates from a depth below the surface to the limits of the atmosphere.

Thus if w denote the caloric equivalent of a kilogram-meter, and dr the height of the atmosphere, we shall have the following differential relation between the internal heat and gravitational work upon a kilogramme of air: $-\zeta_p dT = wdr$, in which as before ζ_p is the specific heat of the gas under constant pressure and dT is the change of absolute temperature. When the kilogramme of air is elevated above the surface dr, where the force of gravity is g', we shall have

$$-\zeta_p dT = w\frac{g'}{g}dr = wadr \tag{44}$$

The total amount of heat given up by the element in ascending from the center of the sphere to the surface will be given by

$$-\int_{T_0}^{T} \zeta_p dT = w\int_{r=0}^{r=R} adr = \nu R, \tag{45}$$

where ν is a small numerical coefficient, which must be found by successive approximations. If the force of gravity at the surface of the sphere were $G = \beta g$ we should have

$$\zeta_p dT = -w\beta adr, \tag{46}$$

$$\zeta_p T_0 = -w\beta\int_0^R adr = w\beta\nu R \tag{47}$$

$$\frac{dT}{dr} = -\frac{T_0}{\nu R}\alpha \tag{48}$$

$$\frac{d^2T}{dr^2} = -\frac{T_0}{\nu R}\frac{d\alpha}{dr} \tag{49}$$

The relation between density and temperature can be deduced from the celebrated equation of Poisson,

$$\frac{P_0}{P} = \left(\frac{T_0}{T}\right)^{3.44} \tag{50}$$

which may be put in the form

$$\frac{\sigma}{\sigma_0} = \left(\frac{T}{T_0}\right)^{2.44} \tag{51}$$

Substituting in (43) for σ, $\frac{d\alpha}{dr}$ and α their values given by equations (51), (49), and (48), we have

$$\frac{\nu R}{T_0}\frac{d^2T}{dr^2} + \frac{2\nu R}{T_0 r}\frac{dT}{dr} + \frac{3\sigma_0}{R\bar{\sigma}}\left(\frac{T}{T_0}\right)^{2.44} = 0. \tag{52}$$

Putting $\frac{r}{R} = \xi$ and $\frac{T}{T_0} = \eta$, this equation may be written

$$\frac{d^2\eta}{d\xi^2} + \frac{2}{\xi}\frac{d\eta}{d\xi} + \frac{3\sigma_0}{\nu\bar{\sigma}}\eta^{2.44} = 0. \tag{53}$$

which is the form given by Ritter. We may determine the three constants of this differential equation, as well as the two constants of integration as follows. By the equation $M = \frac{4}{3}\pi\bar{\sigma}R^3$, the constant $\bar{\sigma}$ is to be taken as known, when R and M are given, as we here assume; and the value $r = R$, $\xi = 1$, corresponds to $\alpha = 1$, and by equation (48)

$$\frac{dT}{dr} = -\frac{T_0}{\nu R}, \quad \text{or} \frac{d\eta}{d\xi} = -\frac{1}{\nu}.$$

Thus the constant ν is equivalent to the negative reciprocal value of $\frac{d\eta}{d\xi}$ for $\xi = 1$. Moreover, $T = 0$, and $\eta = 0$, for

$\xi = 1$. The value $r = 0$, or $\xi = 0$, corresponds to the value $\alpha = 0$, and hence by (48) $\frac{dT}{dr} = 0$, or $\frac{d\eta}{d\xi} = 0$. Finally, $T = T_0$, or $\eta = 1$, for $\xi = 0$.

If now we seek to find the law, according to which ξ and η change, and represent the result by a curve which is corrected by successive approximations till it satisfies the above differential equation in all its points, we shall have the following numerical values, computed by Ritter: —

$\xi = 0$	0.1	0.2	0.3	0.4	0.5	0.6	
				0.7	0.8	0.9	1.0
$\eta = 1$	0.95	0.83	0.68	0.52	0.38	0.27	
				0.18	0.10	0.045	0.

(A)

The constants $\nu = 2.4$, and $\frac{\sigma_0}{\bar{\sigma}} = 23$.

By means of these results and equations (51) and (48) we derive the curves which $\frac{\sigma}{\sigma_0}$, and α represent geometrically. In this way we find the numbers given in the following table:

$\frac{r}{R} = 0$	0.1	0.2	0.3	0.4	0.5	
		0.6	0.7	0.8	0.9	1.0
$\frac{\sigma}{\sigma_0} = 1$	0.88	0.64	0.39	0.20	0.10	
		0.040	0.015	0.0038	0.00054	0.
$\alpha = 0$	2.1	3.5	3.9	3.6	3.2	
		2.5	2	1.6	1.2	1.

(B)

In the case of the Sun, where the central density is, on the gaseous theory, 23 times the mean value, we have the density in units of the mean density and of water respectively: —

$\frac{r}{R} =$	0	0.1	0.2	0.3	0.4	
	0.5	0.6	0.7	0.8	0.9	1.0
$\frac{\sigma}{\bar{\sigma}} =$	23	20.24	14.72	8.97	4.60	
	2.30	0.90	0.345	0.0874	0.01242	0.
Spec. gr. =	32.2	28.34	20.61	12.56	6.44	
	3.22	1.29	0.483	0.12236	0.017388	0.

(C)

It will not be necessary to insert a diagram illustrating these functions, as the resulting curves are similar to those found by Lane, and reproduced in Part I. And since the temperature curves deduced from

$$T = T_1 \sigma^{k-1} \tag{54}$$

depends directly on that of the density, they will also be similar to those given by Lane. But it should be pointed out that, while Lane's density curve depends on the value of k, and in derivation is independent of the law of radiation, Ritter's curve on the other hand depends on Poisson's law of radiation, and is independent of the value of k. The fact that the curves obtained by two such widely different processses agree so closely, may be taken to show that the whole theory of gaseous bodies despite its difficulty, is in a highly satisfactory state. It is easy to see that the density is a function which follows a complex law, varying reciprocally as $\frac{r}{R}$. To inquire into the theoretical nature of this curve, let us express the density in units of the central density σ_0, as in equation (B), and then we shall have

$$\sigma = \varphi \left(\frac{R}{r}\right) \tag{55}$$

It is not easy to find the rigorous algebraic expression for this function, but we may express it in Fourier's series as follows: We assume $\sigma = \varphi \left(\frac{R}{r}\right)$ to be finite and continuous between $r = 0$, and $r = R$, and then put

$$\begin{aligned} \sigma = \varphi (x) = \tfrac{1}{2}\, b_0 &+ b_1 \cos x + b_2 \cos 2x \\ &+ b_3 \cos 3x + \ldots . + b_m \cos mx \\ &+ a_1 \sin x + a_2 \sin 2x \\ &+ a_3 \sin 3x + \ldots . + a_m \sin mx \end{aligned} \tag{56}$$

where

$$\left.\begin{aligned} b_m &= \frac{1}{\pi}\int_{-\pi}^{+\pi} \varphi(\beta)\cos m\beta d\beta \\ a_m &= \frac{1}{\pi}\int_{-\pi}^{+\pi} \varphi(\beta)\sin m\beta d\beta \end{aligned}\right\} \qquad (57)$$

$\pi > x > -\pi$, $\varphi(\beta)$ denoting any known value of $\sigma = \varphi(x)$.

Then since the researches of Lane and Ritter furnish σ numerically for given arguments of the radius, x will not exceed unity, and the multiple angles are, of course, to be taken as multiples of radians, $\frac{p}{q}(57°.3)$, where p denotes the multiple of the angle, and q the number of parts into which the radius is subdivided.

Assuming the transformation here indicated, we may inquire into the law of density when the radius has shrunk from the loss of heat.

The new density curve will obviously be given by an equation of exactly the same form, $\sigma' = \varphi\left(\frac{R'}{r'}\right)$. The internal distribution of temperature in the first case will be defined by $T = T_1\sigma^{k-1}$; in the second case, by $T = T_1'\sigma'^{k-1}$; whence we see that the laws of distribution of density and temperature are the same after shrinkage has taken place as before.

Some persons who do not fully understand the problem under consideration, have claimed that the functions which define the internal distribution of density and temperature change with contraction; that these functions depend upon the linear dimensions of the globe rather than upon the principle of convective equilibrium, and would give a new law of temperature at each stage of the shrinkage.

It will perhaps be evident from the preceding differential equations or from the curves which they satisfy, that the density and temperature are independent of the linear dimensions of the gaseous globe.

Thus, so long as the mass is a perfect gas the forms of the density and temperature curves are rigorously the same after contraction as before. If, however, the radiation were suddenly checked, say by surrounding the gaseous globe with a solid shell impermeable to heat, the internal temperature would soon become more equably diffused; the convective currents would be interrupted or replaced by conduction of some kind, and the nature of the temperature and density curves would be rapidly altered.

When the shell was removed, however, the original conditions would return, and the curves of density and temperature take their usual forms which satisfy the foregoing differential equations. From these considerations we conclude that the distribution of temperature and density remain the same, are represented by functions of the same form, which satisfy the same differential equations so long as the radiating mass is gaseous and condensing under conditions of convective equilibrium.

5. *Elementary Derivation of the Law of Temperature.* Suppose a gaseous globe of radius R_0 and surface temperature T_0 to be held in equilibrium by the pressure and attraction of its particles. Let P_0 be the gravitational attraction exerted upon a thin layer of matter covering a unit surface of the globe, which may be regarded as the base of an elemental cone extending to the center. Then suppose the globe to shrink by loss of heat to a radius R. If the original element of mass now covered a unit surface the pressure exerted upon it would thereby become $P = P_0 \left(\frac{R_0}{R}\right)^2$. But since the area of the initial sphere surface has shrunk to $S = S_0 \left(\frac{R}{R_0}\right)^2$, the area of the elemental conical base into which the matter is compressed has diminished in the same ratio. As the force of gravity is increased while the area upon which it acts is correspondingly decreased, it follows that in the condensed condition of the globe the gravitational pressure exerted upon a unit area is $P = P_0 \left(\frac{R_0}{R}\right)$. The forces counterbalancing the increased

pressure are obviously the resistance due to the increase in the mean density, and a possible change in temperature which might affect the elasticity of the gas. But the surface density of the original mass was σ_0', and hence we have $\sigma' = \sigma'_0 \left(\frac{R_0}{R}\right)^3$.

By hypothesis the equilibrium of the globe is maintained by the elastic force of the gas under the heat developed by the gravitational shrinkage of the mass. If therefore the globe was in equilibrium when the mass had a temperature T_0, to remain in equilibrium in the condensed condition, T_0 must be multiplied by $\frac{R_0}{R}$. As T_0R_0 is a constant, we may write the law of temperature

$$T = \frac{K}{R} \tag{58}$$

So great is the author's confidence in the significance of physical causes, that he does not hesitate in the belief that this simple formula expresses one of the most fundamental of all the laws of Nature.*

Its application of course is confined to gaseous bodies, but it is safe to assume that millions of stars and nebulae approximate this condition closely, and give this law profound import. It is obvious that the equations of pressure and temperature above applied to the external layer of the globe will apply equally well to any concentric layer of which the globe is made up, and thus it is unnecessary to consider anything more than the surface layer.

Contemplating now the fundamental law of temperature, $T = \frac{K}{R}$, we see that it will obviously hold true for the mean temperature of the condensing mass, whatever be the law of internal density and temperature, so long as the globe is wholly gaseous, and maintained in convective equilibrium by

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* A distinguished foreign astronomer, writing under date of April 29, 1899, says: "I am profoundly glad that you have had the courage to generalize. The fear is that our outstanding men of science will go on accumulating data till they became crushed under the load of their observations. You call your law a fundamental law. I am sure it is so."

free radiation into surrounding space. For if the globe be made up of i isothermal layers of uniform density λ_i, temperature T_i, and mass m_i; then a theorem of the form

$$T_i = \frac{K_i}{R_i} \tag{59}$$

will hold for each layer of the globe. And for the mean temperature of the whole we shall have

$$T = \frac{1}{M} \sum_{i=o}^{i=i} \frac{K_i\, m_i}{R_i} \tag{60}$$

When the mass condenses the temperature of each layer rises proportionally, and we have the same law as before.

The above reasoning assumes that the globe is composed of one kind of gas throughout, and that its properties are the same under all conditions of temperature and pressure. The Sun and stars appear to be compounded globes of different gases which freely interpenetrate one another. If such interpenetrating globes be of unequal dimensions under given conditions of temperature and pressure, as seems probable, on account of the elements rising to heights inversely as the atomic weights, then the relative percentage of the several elements which would appear in a layer of the mixed gas would be a function of the distance of that layer from the center. As the specific heats of the different elements are unequal, we may take each layer of mass m_i to have an average specific heat ζ_i, the effects of which may be included in the constants K_i, and the resulting value written K_i'. The temperature formula for any layer would thus become $T_i = \frac{K'_i}{R_i}$, and the mean temperature of the globe would be

$$T = \frac{1}{M} \sum_{i=0}^{i=1} \frac{K_i' m_i}{R_i} \tag{61}$$

The mass of any layer is $m_i = \frac{4}{3}\, \pi\, \lambda_i\, (R_i^3 - R^3_{i-1})$, and the amount of heat in any such layer is $m_i\, \zeta_i\, T_i$.

$$\text{Hence } T = \sum_{i=0}^{i=i} \frac{m_i \zeta_i T_i}{\sum\limits_{i=0}^{i=i} m_i \zeta_i}, \text{and as } \sum_{i=0}^{i=i} m_i \zeta_i = C,$$

our final equation takes the form

$$T = \sum_{i=0}^{i=i} \frac{m_i \zeta_i}{C} \frac{K'_i}{R_i} \tag{62}$$

In this expression R_i is the only secular variable, and hence the fundamental law of temperature retains its original form. If, however, the gases diffused according to a new law when the mass shrunk, it would require us to take account of this slowly modifying cause. For considerable intervals it might be neglected, but for very great periods an error would at length develop and necessitate a new integration. The form would then be $T = \frac{K(1+\beta t)}{R}$, where t is the time and β a small secular coefficient. It thus appears that the law $T = \frac{K}{R}$ holds for every layer of the Sun's mass, and consequently for the mean temperature of that globe. It is not probable that unknown conditions arising in gaseous stars and nebulae are likely to render this law appreciably inexact, and hence we are, I think, justified in regarding it as one of the most fundamental as it is the most simple of all the laws of Nature.

The question will doubtless be asked how far this law is applicable to the evolutionary history of the Solar System. We may observe that as the Sun is still gaseous, it now has a mean density a little greater than one thousand times that of atmospheric air. As the molecules in a vacuum produced by the air pump still roughly follow the laws of gases when the density is reduced to about one-millionth of the ordinary density, we see that gases may undergo a change of density of a billionfold without wholly invalidating their known physical laws. It thus appears that our Sun would probably behave sensibly as a gas when its radius was one thousand times larger than at present; or that the Solar Nebula has been gaseous since it came within the orbit of Jupiter. Even if the above law of temperature hold only within the thousand-fold radial limits here pointed out, it will still admit of wide application throughout the heavens. In the present state of our knowledge of the laws of gases, we refrain from any attempt at fixing more definite limits to the Solar Nebula, which would also depend on the temperature of the mass. For if the mass could be kept sufficiently heated it might extend its bounds far beyond the present limits of the Solar system.

In concluding these remarks, the following curious illustion of a reversible process is thought to be worthy of attention. Imagine a huge pipe made of some material impervious to heat laid from the center of a great hot star like Canopus to the center of the Sun, and suppose the two ends to be closed by non-fusible pistons which freely transmit the heat communicated along the pipe. Heat will flow steadily from the hotter to the cooler source, and as the center of Canopus is assumed to be much hotter than the center of the Sun, the material at the latter point will receive a supply of heat which will tend to elevate the temperature of the Sun's mass; but as heat cannot be supplied to the gaseous globe without expanding its dimensions, the result will be an increase in its diameter and a corresponding fall in its temperature. If the flow of heat along the pipe is sufficiently great (it must of course surpass the amount lost by surface radiation), and kept up long enough, the compact mass of the Sun will be expanded into a vast diffuse nebula filling the planetary orbits; and if the pipe then be intercepted the cold rare mass will again slowly condense and rise in temperature, and the planetary system will be formed anew!

6. *Conclusions based upon the fundamental law of temperature.* The following conclusions seem to be legitimate inferences from the remarkably simple law of nature treated above.

(a.) *The diffused nebulae are near the temperature of space.* In the formula $T = \frac{K}{R}$, K is different from each body, but always finite, and hence when R is infinite T is zero.*

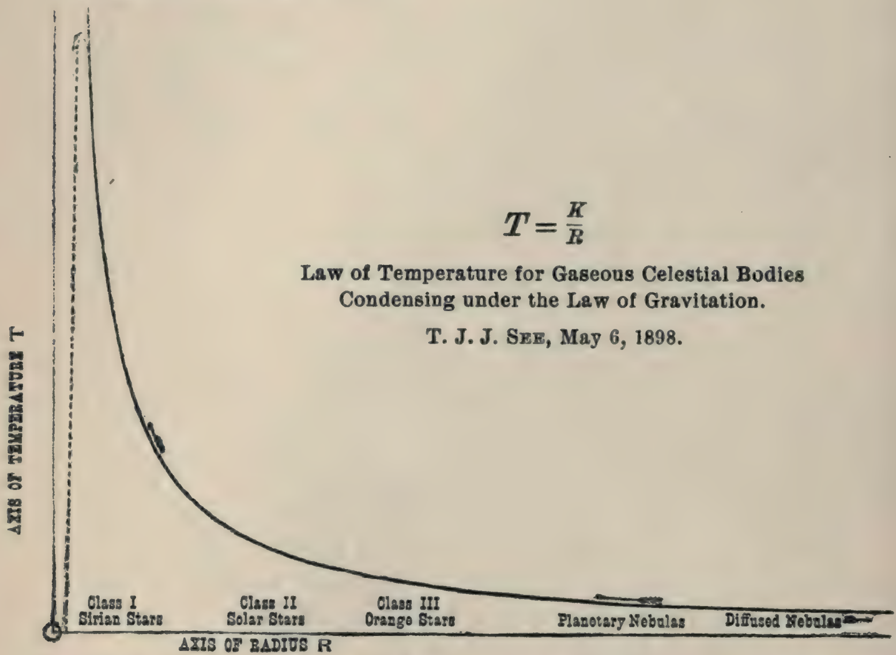
* Cf. Astronomical Journal, No. 458.

Thus the diffused nebulae are near the temperature of space, or approximately — 273° C. This may also be inferred from other considerations. If such diffused masses were appreciably heated, they would soon cool off; and, besides, molecules on their outskirts having sensible molecular velocities, would escape into interstellar space. How the light of such masses is maintained is quite unknown, but it seems not improbable that it is due to electric luminescence such as we observe in the tails of comets, which also shine at temperatures approaching the absolute zero. We may therefore suppose the diffused and irregular nebulae, as well as the milky nebulosity so abundantly scattered over the sky, to be intensely cold. It is an impressive fact that hydrogen and *nebulium* are the only elements recognized in the nebulae, and all other elements presumably present are wholly non-luminous.

(b.) *Stars of the first class are at the maximum temperature and already condensed to the smallest bulk consistent with the laws of gaseous constitution.* The high temperature of the Sirian stars is inferred generally from the nature of the light emitted by these bodies, and in the particular case of Sirius, is proved by the enormous radiation of that star compared to that of our Sun. Thus, while the mass of Sirius is only twice that of our Sun, its radiation is shown to be forty or fifty times the greater of the two bodies. It follows, therefore, that the Sirian stars are intensely hot. By the above law of temperature such heat can be developed and such radiation maintained only when the radius of the condensing mass is relatively small. The Sirian stars have therefore already shrunk to small bulk, and the contention recently current among astrophysicists, that the Sirian stars are of great bulk, and resemble nebulae, can no longer be supported.

Such tremendous radiation as we observe could not, it appears, be maintained by the gravitational shrinkage of the mass, except when the radius is small, and the force of gravity correspondingly enormous. As respects volume therefore as well as temperature the Sirian stars are as far removed from the nebular condition as possible; and any spectral parallel between these two classes of objects should be explained in some other way. The diffuse nebulae are cold, infinitely rare, and almost free from pressure; the Sirian stars are intensely hot, relatively dense, and subject to enormous gravitational pressure.

The Astronomical Journal, No. 455.



CURVE OF TEMPERATURE FOR GASEOUS STARS AND NEBULAS, A RECTANGULAR HYPERBOLA REFERRED TO ITS ASYMPTOTES.

(c.) *Stars of the second class have not yet reached the maximum temperature.* Stars of the second class, of which our Sun is an example, are conceded to be at lower temperatures than those of the first class, and the question arises whether their temperatures are rising or falling. The Sirian stars are surrounded by dense hydrogen atmospheres, which produce the heavy absorption observed in their spectra. As the heights of atmospheres of gases of different molecular weights under any given condition are known to be inversely as the molecular weights, it follows that when a star is so far condensed that gravity is intense, the outer atmosphere ought to be of hydrogen, such as we observe in the Sirian stars. The heavier elements in the Sirian stars are pressed down by gravity, and their spectral lines are either faint, or entirely absent. Now if our Sun had already passed through the Sirian stage, and the temperature was falling, the hydrogen atmosphere which had been separated from the other elements by the effects of gravity ought still to surround its globe. As all the elements in the Sun are fairly evenly mixed, such heavy vapors as calcium and iron mixing freely with those of light elements like hydrogen and helium, we infer that our Sun has not yet passed through the Sirian stage of development. The lower temperature of solar stars thus indicates an earlier condition than that met with in the Sirian stars.

(d.) *Stars of the third class are at a still earlier stage of development.* This inference is based upon well known spectral phenomena which connect classes I, II, and III. If the first class stars are related to the second class stars as stated above, the continuity of spectral lines show that the third class stars are still younger, and further from the maximum of their temperature curves. It is a fact of great significance that the Milky Way, presumably the oldest part of the visible creation, is composed almost wholly of Sirian stars. On the other hand, the solar stars and to a greater extent the orange stars, seem to cluster about the poles of the galaxy. The orange stars are in fact relatively thickest in those regions of the sky which are poor in stars, like Hydra, Microscopium, etc. This depth of color of the stars remote from the Milky Way frequently attracted the attention of the writer while occupied with the survey of the Southern hemisphere. If the reddish stars have a larger bulk than the older more condensed stars, they would naturally receive more accretions of dark matter from surrounding space, the chance of collision at periastron being thereby increased, and one might naturally explain in this way the greater variability of the third class stars.

(e.) *Present and Past Temperatures of the Sun.* If we adopt the effective temperature of the Solar photosphere experimentally determined by Wilson and Gray (*Phil. Trans.*, 1894), which is about 8000° C., we see that when the Sun's radius was twice as great as at present, the effective temperature, by the above law, was about 4000° C.; and when the radius had eight times its present value, the temperature was only 1000° C., which would not fuse the more refractory metals. The following table shows the effective temperature of the solar nebula when it extended to the several planets: —

	(Absolute Temperature.)
Present solar surface	8000° C.
Mercury	92° C.
Venus	53° C.
Earth	40° C.
Mars	24° C.
Jupiter	7° C.
Saturn	4° C.
Uranus	2° C.
Neptune	1° C.

The excessively low temperature of the solar surface when it reached the orbits of the several planets can hardly fail to excite our astonishment. The temperature was always much below zero, and the density of the mass necessarily very small. About the only escape from such low temperatures for the planets at their formation is to suppose that the Sun has long passed its maximum temperature, and as now cooled down does not allow us to trace the past history of its temperature; but of course such an hypothesis is embarrassed by many difficulties. Indeed it seems positively contradicted by the existence of life upon our globe which could hardly have deleloped as Geology shows it did develop, had the Sun ever been enormously hotter than at present.* The conclusion that the planets were formed at very low temperatures therefore seems irresistible.

* Some of these conclusions have been anticipated by Ritter, who remarks how contrary they are to current theories (herschende ansichten), yet it does not appear that he made any very serious effort to overthrow the errors which have been handed down by tradition.

(f.) *Temperatures of the Great Planets.* As experiments upon the secular shrinkage of great masses cannot be made in our laboratories, it is fortunate that the solar system offers to our observation large as well as small planets which may be taken to be approximately of the same absolute age. We find the smaller planets such as the Earth, Venus, Mars, and Mercury, already solid, while the great planets Jupiter, Saturn, Uranus, and Neptune, are apparently still gaseous, if not actually rising in temperature. A similar comparison holds for the Moon and Jupiter's satellites which are much more advanced in their development than the planets about which they revolve. The law of temperature shows that if bodies like Jupiter and Saturn are gaseous, they have not been hot in the past, but may become so hereafter. There is some spectral indication of inherent luminosity in Uranus, and hence all the great planets are probably still rising in temperature. As the temperatures of these masses were originally near the absolute zero of space, we are not to think of them as cooling, but rather as having slowly heated up ever since their separation from the solar nebula.

The inferences of Kant, Zöllner, and Proctor, as well as the original assumption of Laplace, all implying an initial high temperature, it is needless to say, are wholly unauthorized. It is possible and perhaps even probable, that some of the great planets, especially Jupiter and Saturn, may eventually become self-luminous.

The problem as to how closely the purely gaseous theory conforms to the actual state of the heavenly bodies is very important, but unfortunately difficult to answer with confidence. On the one hand, the purely gaseous theory leads to a height of 27.5 Kilometres for the terrestrial atmosphere; on the other, observations of meteors, which disclose the fact without regard to theory, show that it extends in a rarified state to a height of at least 200 Kilometres. From this well-established deviation of theory from phenomena, it would appear that the purely gaseous atmosphere extends to its proper height, and is then overlaid by another layer in the ultragaseous state. Presumably this upper ultragaseous atmosphere is one in which the molecules have a long free path, and are in fact projectiles from the gaseous atmosphere beneath. Moving almost without collision, these molecules may be regarded as free projectiles shot out with velocities which carry many of them to an average height of some 200 Kilometres. Meteors colliding with the upper part of this ultragaseous atmosphere would of course finally be consumed very much as if the mass were denser and obeyed the laws of fluid equilibrium.

The Solar Corona is the analogue of the upper terrestrial atmosphere; and similar gaseous appendages doubtless surround the planets and other heavenly bodies. But since the limbs of Jupiter and Saturn, which have been studied by means of eclipses and occultations of their satellites, appear telescopically sharp and almost perfectly opaque, it is not probable that these rare atmospheres in comparatively cold bodies like the great planets, have anything like the relative extent of the Corona, which is kept expanded by the intense heat of the Sun. Yet it may be assumed that all bodies, planets, comets, and stars alike, have the two strata in some proportion. In the case of the stars, which especially concerns us here, we may suppose, on the analogy of the Sun, that their Coronas give very little light and heat, and hence that the laws of gases apply with considerable accuracy to their radiations. It is certain that a Corona does not seriously obstruct the radiation, and equally clear that no sensible amount of heat can arise from the condensation of such a rare medium. The laws of gases ought therefore to apply to the condensation of stars which are well advanced, but in the case of diffuse nebulae the extreme tenuity of the medium relieves it of the laws of fluid pressure and renders the radiations practically free in all directions; and the theory of convective equilibrium is not required.

(g.) *Cause of the darkness of the companions of such stars as Sirius and Procyon.*

The secular shrinkage of the sun's radius will cause a steady rise in its temperature, and when the body has reached the stage of Sirius it will shine with an intensely blue light, like that emitted by stars of the first class. The temperature will go on rising * till a small radius is attained, and finally when the dense mass, intensely hot, becomes incapable of further shrinkage, from increase of resistance in molecular forces, a cooling and liquefaction will rapidly take place. A condition of darkness thus follows close upon a period of intense brilliancy; and hence the darkness of such bodies as the companions of Sirius, Procyon, and Algol.

Here the smaller masses, as in the solar system, have developed most rapidly. The theory of the ages of the stars here adopted enables us to explain the colors and relative masses of the double stars. On this point Ritter has gone astray, by concluding that in double stars the companion, usually bluish in color, has a larger mass than the principal star, which is usually of a reddish or orange tinge. This view is positively contradicted by the relations of the masses determined from actual measurement in the cases of η Cassiopeiae, Sirius, Procyon and, α Centauri, the only systems in which the relation of the masses has been investigated. As each of these systems is a typical double star, the rule of assigning the fainter star the smaller mass — a mere inference of common sense — will undoubtedly hold good generally. And since the spectra of the companions of double stars are generally of the first class, while those of the principal stars are of the second class, the result also conforms to the theory of the ages of the stars adopted above.

Certain obscure companions of double stars recently discovered by the writer in the southern hemisphere, as well as the historical examples of Sirius and Procyon, lead him to

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* Professor Perry, of the Royal College of Science, London, has pointed out in a letter to Sir Norman Lockyer (*Nature*, July 13th, 1899; reply by the author in *Nature* of September 28th), some reasons for thinking that our sun has long since passed the period of maximum temperature. He thinks that after the central density exceeded one-tenth that of water, the mass could no longer be considered a perfect gas; but it seems to the author that Professor Perry regards too lightly the effect of the tremendous temperature of the sun, which necessarily increases the "perfection" of the gas, and perhaps to an enormous extent. He concurs however in the author's views that old stars have their radiating layers near their surfaces, and that they radiate more rapidly than young stars. The other interesting points suggested by Professor Perry may be reserved for future research.

believe that the number of such dark bodies is enormous; and a satisfactory explanation of their condition is therefore a *desideratum* of science. The suggestion here thrown out that the smaller masses condense more quickly, and thus become dark while the large bodies are intensely brilliant seems to accord with all known phenomena of nature.

(h.) *Absorption of Light in Space.* If it be conceded that the nebulae are cold and that comparatively very few of them are luminous, we shall be driven to the conclusion that the heavenly spaces are more or less filled with dark or faintly luminous matter. This matter appears telescopically as a faint haze on the background of the sky, or as diffuse nebulosity in photographic impressions of the vault of the heavens. In any case such cosmic clouds of dark or semi-opaque matter however rare act like a fog in intercepting some portion of the light from distant regions of creation, and thus ultimately limit the depths to which our telescopes can penetrate. On this account it may never be possible to extend our exploration of the universe beyond a certain finite distance. Struve's celebrated problem of the bounds of creation, in which he discussed the absorption of light arising from the imperfect elasticity of the luminous ether, thus appears more difficult of solution than ever. He showed that if the number of stars be infinite, and they be scattered promiscuously throughout space, and no light be absorbed by the ether, then the whole face of the sky would necessarily glow like the points now occupied by the stars. As the sky is very dark even in the regions most crowded by the stars, it follows either that the universe is not infinite or that light is absorbed or interceped by dark masses scattered throughout the immensity of space. Since we now have for the first time satisfactory evidence of the existence of vast clouds of cosmical dust, which intercept the light of distant stars, we know that the luminiferous ether is not the only cause which extinguishes the light of distant regions of creation. Thus even if the universe of stars be infinite we may never be able to discover this fact, since opaque masses limit the depth to which our telescopes can penetrate.

The significance attached to any line of research naturally varies according to the taste of the investigator, but we believe it is generally allowed that speculative inquiries founded on mechanical laws are essential to the development of Physical Science, and hence have not hesitated to apply the mechanical theory of heat to some of the most interesting phenomena of the heavens.

Issued February 5, 1900.

SOME ILLINOIS BEES.*

Charles Robertson.

Andrena hirticeps Sm.

Andrena hirticeps Smith, Brit. Mus. Cat. Hym. **1**: 116. ♂. 1853.

♀. — Black; pubescence black, except on thorax above, on vertex and usually about insertion of antennae, where it is ochraceous; clypeus shining, coarsely punctured, except a median raised line; process of labrum semicircular; third joint of antennae about equaling next two joints together, flagellum dull testaceous beneath; wings fusco-hyaline, apical margins clouded; nervures and stigma fusco-ferruginous, second submarginal cell about as long as third to second recurrent nervure; abdomen shining, almost impunctate except on bases of segments, no pubescent fasciae. Length 12–13 mm.

Carlinville, Illinois; 24 ♀, 27 ♂ specimens, the sexes taken in copula. I have regarded the male as that of *A. vicina*, and the female as only a variant form. The true *A. vicina*, I think, does not occur here. The male, which, no doubt, resembles the above, I think will be found to want the black hairs on the head. But for the description of the male, I would say that *A. errans* is the same as *A. hirticeps*.

Andrena viciniformis n. sp.

♀. — Black; head, thorax and femora clothed with fulvous pubescence which is brightest on scutellum, palest beneath, a few blackish hairs about ocelli and on clypeus, floccus pale, tibiae and tarsi with blackish pubescence, the scopae on hind femora and tibiae, however, pale beneath; clypeus shining, coarsely punctured, a median raised line impunctate; process of labrum semicircular; third joint of antennae about equaling next two together; wings fusco-hyaline, nervures fusco-ferruginous, second and third submarginal cells subequal;

* Presented to The Academy of Science of St. Louis, in abstract, January 22, 1900.

abdomen shining, nearly bare and nearly impunctate, anal fimbria dull fulvous. Length 10–12 mm.

♂. — Resembles the male of *A. hirticeps*, but the black hairs on vertex and about eyes are wanting, and the second and third submarginal cells are subequal. Length 9 mm.

Carlinville, Illinois; 18 ♀, 2 ♂ specimens. This may be the same as *A. dunningii*.

ANDRENA MACOUPINENSIS n. sp.

♀. — Black, tips of four anterior tarsi and hind tibiae and tarsi ferruginous; pubescence thin and pale; clypeus convex, finely roughened and closely punctured on the sides, in the middle smooth, shining, coarsely and sparsely punctured; process of labrum large, emarginate; front before ocelli finely striate; lateral grooves broad, extending below antennae, filled with pale pubescence; third joint of antennae longer than next two together, fourth joint shorter than fifth, flagellum dull testaceous beneath; mesonotum and scutellum sparsely punctured, finely roughened except on the discs which are smooth and shining; inclosure of metathorax finely and evenly roughened; wings yellowish hyaline, nervures and stigma dull honey yellow, second submarginal narrowed above, receiving recurrent nervure beyond middle, about one-half as long as third; hind tibiae and metatarsi rather broad, tibial scopa short, dense, not very plumose; abdomen somewhat shining, minutely roughened and finely sparsely punctured, clothed with rather long thin pubesence forming thin whitish fasciae on margins of segments, anal fimbria ochraceous. Length 11 mm.

Carlinville, Illinois; 2 ♀ specimens. This species closely resembles *A. mandibularis*, but the clypeus, mesonotum and scutellum are more shining, pubescence thinner and paler, facial grooves longer, broader, with paler pubescence, third joint of antennae longer, hind legs stouter, inclosure of metathorax larger, less rugose, etc.

ANDRENA SALICACEA n. sp.

♀.— Black; clothed with thin pubescence, dirty white above, pale below, showing a little fuscous on the tibiae; clypeus convex, finely roughened, with rather large and sparse punctures; process of labrum long, narrow; front below ocelli finely striate; facial grooves narrow, extending below antennae, appearing fulvous; antennae black, short, joint three longer than four and five together, these subequal; mesonotum and scutellum finely roughened, rather sparsely punctured, not shining; metathorax rugose reticulated, inclosure small, quite rough; wings subhyaline, nervures honey-yellow, stigma darker, second submarginal cell about half as long as third, receiving recurrent nervure just beyond middle; abdomen smooth, shining, almost impunctate, especially the first segment, with thin pale pubescence, segments 2–4 with narrow pale-testaceous margins and thin whitish fasciae, anal fimbria blackish. Length 10 mm.

Carlinville, Illinois; 2 ♀ specimens. This species also resembles *A. mandibularis*.

ANDRENA NASONII Rob.

Andrena nasonii Robertson, Trans. Am. Ent. Soc. **22**: 120. ♀. 1895.

♂. — Closely resembles the female; abdomen more shining, pubescent fasciae almost obsolete; face narrowed below; clypeus finely roughened, with rather coarse, shallow punctures, bearded with long, thin, white pubescence; antennae long, joint three about as long as four, shorter than five. Length 6–8 mm.

Carlinville, Illinois; 15 ♀, 4 ♂ specimens.

ANDRENA ROBERTSONII D. T.

Andrena serotina Robertson, Trans. Am. Ent. Soc. **20**: 148. ♀ (not ♂). 1893.

♂. — Closely resembles the female; abdomen less fasciate with pubescent bands; clypeus yellow; third joint of antennae longer than fifth; cheeks narrow, without obtuse angle; sixth ventral segment of abdomen with reflexed dentiform angles. Length 7 mm.

Carlinville, Illinois; 41 ♀, 7 ♂ specimens. Resembles the male of *A. bipunctata*, but may be readily distinguished by its cheeks being more narrow, without obtuse angle, more rugose inclosure of metathorax and dentiform reflexed angles of sixth ventral segment.

Andrena corni n. sp.

♀. — Closely resembles *A. pruni* ♀ in size and color; middle of mandibles rufous; process of labrum triangular, truncate; clypeus more closely and finely punctured, less shining, more pubescent, median raised line less evident, joint three of antennae longer than next two together, facial foveae broad, not widely separated below from eye margin; inclosure of metathorax more rugose; abdomen less shining, more closely punctured, legs more ferruginous. Length 11 mm.

Carlinville, Illinois; 1 ♀ specimen.

Andrena andrenoides Cr.

Parandrena andrenoides Robertson, Trans. Acad. Sci. St. Louis. **7**: 337. 1897.

Andrena wellesleyana Rob.

Parandrena wellesleyana Robertson, Trans. Acad. Sci. St. Louis. **7**: 337. 1897.

When this name was proposed it was stated that it was little more than a section of *Andrena*. It is proposed here to reduce it to that rank. It is certainly a natural group in which the two above species have originated from a common ancestor whose wings had only two submarginal cells. Nevertheless, except as an expedient for separating the species having only two submarginal cells, we are hardly justified in giving a special name to this group of *Andrena* unless we are going to divide the genus into several named sections.

The second transverse cubital nervure is the most unstable element in the venation of bees. Its presence is not constant in ordinary species of *Andrena*, as I have found it wanting in specimens of *Andrena platyparia*, *solidaginis*, *bipunctata*, *hippotes*, *robertsonii* and *claytoniae*. Its obliteration seems to be constant, and of quite independent origin, in species referred to *Biareolina* Dours, *Callandrena* Ckll. and *Parandrena* Rob. To establish a new genus for every one, or every set, of these anomalous Andrenas, now seems to me to be unnecessary.

Iomelissa n. g.

This is proposed for the reception of *Andrena violae* Rob. Scopae, facial foveae and venation as in *Andrena*, the basal nervure sometimes ending before the transverse median; clypeus produced, third joint of antennae longer than next two together, mouth parts long, maxillary palpi six-jointed; labial palpi four-jointed, the joints long and subequal; tongue long, filiform, pubescent.

This may be the same as *Cilissa americana* Sm. The male sometimes has a small yellow spot on the clypeus, and on each side of the face.

COLLETES BREVICORNIS Rob.

Colletes brevicornis Robertson, Trans. Acad. Sci. St. Louis. **7**: 315. ♂. 1897.

♀. — Agrees with the male in all respects, except that the pubescence on the thorax above is mixed with blackish. Length 9 mm.

Carlinville, Illinois; 5 ♀ specimens.

The third joint of antennae is longer than any except the last, and, of course, the scape; second submarginal cell equal to, or a little shorter than, the third, receiving the first recurrent nervure a little before the middle; nervures usually darker than indicated in original description.

SPHECODES PIMPINELLAE n. sp.

♀. — Black, flagellum, labrum, mandibles, tegulae, tibiae, tarsi and abdomen red; mandibles dark at tips, with a dentiform angle; head broader than thorax; face closely and rather finely punctured, the clypeus with more sparse and more coarse punctures; mesonotum with median impressed line, roughened and indistinctly punctured in front, the disc shining, somewhat metallic, punctures more distinct; metathorax shining, coarsely reticulated, with a semicircular inclosure above; wings subhyaline, nervures and stigma fuscous; second submarginal cell narrow; first recurrent nervure uniting with second transverse cubital; abdomen shining, almost impunctate, fifth segment blackish. Length 7 mm.

Carlinville, Illinois; 1 ♀ specimen.

HALICTUS ARCUATUS Rob.

Halictus arcuatus Robertson, Trans. Am. Ent. Soc. **20**: 145. ♀. 1893.

♂. — Black, a transverse spot on clypeus, labrum, mandibles except base, tegulae in front, knees, edges of anterior tibiae and all the tarsi whitish, the spots on tegulae and knees sometimes wanting; antennae long, submoniliform, black; head and thorax closely and finely punctured; scutellum subbilobed, with two mammiform eminences, metathorax very coarsely and strongly rugose reticulated; wings hyaline, nervures testaceous; abdomen shining and rather sparsely punctured on first segments, margins of segments depressed, narrowly pale testaceous, segments two and three with more or less evident, thin, interrupted, basal pubescent fasciae. Length 7–9 mm.

Carlinville, Illinois; 5 ♂ specimens.

HALICTUS SIMILIS Sm.

Halictus similis Smith, Brit. Mus. Cat. Hym. **1**: 69. ♀. 1853.

♂. — Closely resembles the male of *H. arcuatus.* It is more slender, the abdomen more shining, less closely punctured, antennae testaceous beneath, a pale spot on tubercles, tibiae pale at base and apex. Length 8 mm.

Carlinville, Illinois; 1 ♂ specimen.

NOMADA SALICIS n. sp.

♂. — Mandibles simple; antennae short, fourth joint twice as long as third, joints 7–12 short; head and thorax closely punctured, abdomen shining, scutellum bilobed, basal nervure ending beyond transverse median, apical segment of abdomen bifid. Black, the lower part of face, mandibles except tips, labrum, scape in front, front and lower border of pleura, tubercles, two spots on scutellum, yellow; anterior and middle coxae in front, the knees, anterior and middle tarsi, anterior tibiae in front, middle and posterior tibiae at apex, yellow; elsewhere the legs are more ferruginous, inclining to blackish behind on middle and posterior pair; wings hyaline, apical border clouded, nervures and tegulae testaceous; abdomen with six yellow bands, the last two interrupted laterally so as to leave a small spot on each extreme side. Length 8 mm.

Carlinville, Illinois; 1 ♂ specimen.

HERIADES Spin.

H. carinatus Cr. is a *Trypetes*. *H. philadelphi* is a *Chelostoma*. *Osmia bocconis* Say belongs to *Ashmeadiella*.

Florilegus n. g.

This is proposed for the reception of *Melissodes condigna* Cr. It has the general character of *Melissodes*, but the maxillary palpi are moniliform, five-jointed, the joints subequal. The abdomen shows a metallic reflection.

Anthedon n. g.

This is proposed for the reception of *Melissodes compta* Cr. The male has the antennae black, shorter than in *Melissodes*, joints 3 and 4 subequal, the last joint is the longest in the flagellum and is curved and produced to a point. In the female the scopae consist of hairs which are quite simple, not plumose as in *Melissodes*. The fasciae of abdomen are about alike in both sexes. Otherwise as in *Melissodes*.

Melissodes atripes Cr.

Epimelissodes atripes Ashmead, Trans. Am. Ent. Soc. **26**: 63. 1899.

Mr. Ashmead makes this the type of a new genus. His description of the venation is correct for only certain individuals, perhaps a majority, but in some specimens the first submarginal cell is fully as long as the third. The maxillary palpi are four-jointed. This species is closely related to *M. obliqua* Say, which also has the maxillary palpi four-jointed.

Melissodes petalostemonis n. sp.

♀. — Related to and closely resembling *M. communis* Cr., but is somewhat smaller and the mesonotum and scutellum are without black pubescence. Also resembles *M. comptoides*, but the pubescence is less fulvous above, and not dark on the thorax beneath, the front and middle legs, and the hind metatarsi beneath. Length 9–11 mm.

Carlinville, Illinois; 9 ♀ specimens.

Emphor bombiformis Cr.

?Melissodes nigripes Smith, Brit. Mus. Cat. Hym. **2**: 311. ♀ (non ♂). 1854.
Melissodes bombiformis Cresson, Proc. Acad. Nat. Sci. Phil. **1878**: 219 ♂♀.
Emphor bombiformis Patton, Bull. U. S. Geol. Surv. **5**: 476. ♂ ♀. 1879.

The male described by Smith belongs to *Melissodes desponsa*. Cresson and I have supposed that the female was the dark-legged form of *Synhalonia atriventris*, but that would hardly be described as having the pubescence of the legs black. One could hardly account for the statement that the pubescence of thorax was paler than that of the head, nor for mistaking it for the ♀ of *M. desponsa.* Mistaking *M. desponsa* ♂ and *M. bombiformis* ♀ as sexes of the same thing will not seem very strange to any one who will place them side by side. Also, from the statement that the apical margins of the segments were sometimes rufo-testaceous, I suppose that Smith mixed both sexes of the *Emphor*. At any rate, I believe that the above synonymy will be verified.

SYNHALONIA ATRIVENTRIS Sm. form FUSCIPES n. f.

♀. — Differs from the normal form (*S. dubitata* Cr. ♀) in having the tibiae and metatarsi, especially the scopae of hind legs, fuscous or blackish.

SYNHALONIA ROSAE, n. sp.

♀. — Closely resembles the preceding form, but is smaller, the apical half of the second abdominal segment shining and impunctate, the tibial scopa more nearly surrounding that joint, less limited to the exterior of the joint. Length 12 mm.

Carlinville, Illinois; 3 ♀ specimens.

CERATINA CALCARATA n. sp. (?)

? *Ceratina tejonensis* Provancher, Faun. Ent. Can. 812. ♂. 1883.

Ceratina tejonensis Robertson, Trans. Am. Ent. Soc. **22**: 126. ♂. 1895.

Differs from *C. dupla* Say ♂, as far as I can see, only in the hind femora being produced into a triangular tooth. The maxillary palpi are six-jointed. Whether it is the male of a distinct species or a dimorphous male of *C. dupla* I cannot say, but I think the dimorphism has to be proved. According to Mr. Ashmead, *C. tejonensis* has the maxillary palpi four-jointed. He makes it the type of a new genus, *Zaodontomerus.* The name of the local insect is changed on the presumption that Mr. Ashmead's statements are corect.

NEOPASITES ILLINOENSIS Rob.

Phileremus illinoensis Robertson, Trans. Am. Ent. Soc. **18**: 64. ♀♂. 1891.

NEOPASITES HELIOPSIS Rob.

Ammobates heliopsis Robertson, Trans. Acad. Sci. St. Louis. **7**: 352. ♂. 1897.

In the two preceding species the males have the antennae 12-jointed, and pulvilli are present.

EPEOLUS INTERRUPTUS n. sp.

♀. — Black, mandibles except tips, sides of labrum, three basal joints of antennae, tubercles, tegulae, two spots on scutellum, scutellar spines, and legs, except coxae, trochanters and base of hind femora, ferruginous; face about the insertion of antennae, a line on prothorax, two lines on mesonotum, pleura above, sides of metathorax above and postscutellum with appressed whitish pubescence; head and thorax densely punctured, pleura below shining, with coarse not very close punctures; scutellum subbilobed, much surpassing the spines; wings somewhat clouded, especially on apical margins, nervures and stigma black; abdomen with the fasciae of appressed whitish pubescence widely interrupted, wider on the disc and narrower towards the sides; the basal portions on first segment are quite clavate; fifth segment with a patch on each side and a narrow apical border; edges of segments 2–4 subtestaceous; the postscutellum presents a blunt tooth. Length 8 mm.

Carlinville, Illinois; one ♀ specimen.

Issued February 21, 1900.

KINDERHOOK FAUNAL STUDIES. II. THE FAUNA OF THE CHONOPECTUS SANDSTONE AT BURLINGTON, IOWA.*

STUART WELLER.

INTRODUCTION.

The stratigraphic succession of the Mississippian beds at Burlington, Iowa, was first indicated by David Dale Owen † in 1852. At that time the Kinderhook stage or its equivalent had not been defined, but the lower portion of his general section, that portion which is now included in the Kinderhook, was described as follows: —

5. "Band of cellular, buff, magnesian limestone."
4. "Oolitic limestone containing *Gyroceras Burlingtonensis*."
3. "Dark gray, argillaceous limestones (locally hydraulic?)."
2. "Buff, fine-grained siliceous rock, containing casts of *Chonetes*, *Posidonomya*, *Allorisma*, *Spirifer*, *Phillipsia*."
1. "Ash colored, earthy marlites."

At that time Owen included all the strata down to the base of his No. 3, in the "Encrinital Group of Burlington." It is not possible to determine, from his section, the exact thickness attributed to each individual stratum recognized, but their aggregate is indicated in his table as about 100 feet, and the lowest member, No. 1, is about 60 feet.

In 1858 Hall's report on the Geology of Iowa was published,

* Presented in abstract to The Academy of Science of St. Louis, November 6, 1899.

† Rep. on Geol. Wis., Ia., and Minn. 92. (Philadelphia, 1852.)

and the following section given of the rocks at Burlington of the Kinderhook stage, at that time referred to the "Chemung Group."*

Chemung Group.	5. Oolitic bed (often absent) its greatest thickness....................	4 feet.
	4. Argillaceous sandstone with fossils as below, of Chemung species....	6 feet.
	3. Limestone, irregularly-bedded, concretionary and rarely brecciated, with shaly interlaminations; compact, brittle, ash-colored, apparently siliceous. Higher beds more regular and arenaceous; near the base, a thin band of limestone charged with *Chonetes*...........	10 feet.
	2. Fine-grained, siliceous and argillaceous sandstone, with bands of shale, highly fossiliferous; lower half much softer and more argillaceous than the upper part (often shaly).	25 feet.
	1. Soft green shale like that of Portage group, to level of river..........	32 feet.

In 1860 C. A. White published a paper entitled "Observations upon the Geology and Paleontology at Burlington, Iowa, and its Vicinity"† in which the Kinderhook section at Burlington was described, and later, in 1870, while he was State geologist, the section was again described in his official report.‡ In White's section seven beds were recognized, as follows: —

7. Impure limestone, sometimes magnesian, passing gradually into the Lower Burlington limestone. 3 to 4 feet in thickness.

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* Rep. Geol. Surv. Iowa. 1^1: 90. (1858.)

† Jour. Bost. Soc. Nat. Hist. 7: 209–235.

‡ Rep. Geol. Surv. Iowa. 1: 192–193. (Des Moines, 1870.)

6. Light gray oolitic limestone with uniform lithological characters. 2 to 4 feet in thickness.
5. Fine grained yellowish sandstone much like parts of No. 1, often crowded with casts of fossil shells. Maximum thickness 7 feet.
4. Dark gray compact limestone, sometimes slightly arenaceous. It breaks up into small fragments upon exposure, and is very fragmentary even when not exposed to the atmosphere. Maximum thickness 12 feet.
3. Band of oolitic limestone about 3 inches in thickness.
2. Band of compact limestone everywhere crowded with *Chonetes*. 6 inches in thickness.
1. Fine grained sandy shales, varying from bluish clay shale to fine grained yellow sandstone. The upper portion of the bed quite fossiliferous. Greatest thickness actually exposed above river level 82 feet, its total thickness as estimated from well borings 140 to 200 feet.

In his report on Des Moines County in 1895, Keyes * gives the following section of the Kinderhook beds at Prospect Hill, a bluff on the river bank just south of the city of Burlington.

	Feet.
6. Limestone, buff, soft, sandy locally............	5
5. Limestone, white, oolitic......................	3
4. Sandstone, yellowish, soft, fine-grained, highly charged with casts of fossils................	6
3. Limestone, argillaceous, fine grained, with often an oolitic band or thin bed of impure limerock at base..................................	18
2. Sandstone, yellowish, soft, friable, clayey......	25
1. Shale, blue, argillaceous, shown by borings to extend 100 feet or more below river level (exposed)	60

* Geol. Surv. Iowa. 3: 433. (Des Moines, 1895.)

In March, 1899, the writer spent some time in the field studying the Kinderhook section at Burlington, in order to differentiate the fossil faunas of that age there represented, and the following section, which seems best adapted to bring out the faunal succession, has been adopted as the result of observations made at that time. It differs from Hall's and from Keyes' sections only in dividing their No. 3, recognizing as a distinct bed the thin band of impure or oolitic limestone. It differs from White's section only in joining his Nos. 2 and 3, and in dividing his No. 1, the upper sandy, fossiliferous portion being recognized as a distinct bed.

	Feet.
7. Soft, buff, gritty limestone....................	3–5
6. White oolitic limestone.........................	2–4
5. Fine grained, yellow sandstone................	6–7
4. Fine grained, compact, fragmental gray limestone	12–18
3. Thin band of hard, impure limestone filled with *Chonetes*, sometimes associated with a thin oolitic band	$\frac{1}{4}$–$\frac{3}{4}$
2. Soft, friable, argillaceous sandstone, sometimes harder and bluish in color, filled with fossils in the upper portion, the most abundant of which is *Chonopectus fischeri* (N. & P.)............	25
1. Soft blue argillaceous shale (exposed)..........	60

The correllation of the Kinderhook beds at Burlington, as recognized by Owen, Hall, White, Keyes, and the writer, is not a difficult matter, the preceding sections being but different interpretations or different arrangements of the same series of strata. In the following table these five sections are arranged side by side, in such a manner as to correlate the divisions recognized in each, the divisions of the several authors being indicated by numbers only.

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River Level.

The fossils of the Kinderhook beds at Burlington at one time attracted much attention from paleontologists and local collectors, but of late years they have usually been neglected. The first species described from any of the beds was *Gyroceras burlingtonensis*, described by Owen * in 1852 from the oolite bed No. 6 (Weller). A little later (1858), in his paleontology of Iowa, Hall † described and illustrated a number of species of brachiopods and a few pelecypods from the "yellow sandstone" at Burlington.

The most important collection of Kinderhook fossils from Burlington that has been brought together was made by Dr. C. A. White when he was a resident of that city. The "White collection," which is now the property of the University of Michigan, formed the basis for several important papers, devoted to the description of Burlington fossils, by C. A. White,‡ by C. A. White and R. P. Whitfield,§ and by A. Winchell.‖ In these papers many species were described but without illustrations, so that their identification by other observers and from other localities has always been exceedingly difficult or impossible. Many of these species have remained without illustrations up till the present time, a large number of those recorded in the present paper being now figured for the first time.

During the preparation of the descriptions of New York Devonian pelecypods for the Paleontology of New York, Hall ¶ described and illustrated several of the Burlington "Yellow Sandstone" species that were related to New York Devonian species, the figures in most cases being drawn from the type specimens. More recently Keyes** has published upon some of the gasteropods from the Kinderhook beds at Burlington, but his identifications of the species were apparently not based

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* Geol. Surv. Wis., Iowa, and Minn. 581. *tab. 5, fig. 10.*

† Rep. Geol. Surv. Iowa. 1^2.

‡ Proc. Bost. Soc. Nat. Hist. **9**: 8–33. (1862.)

§ Proc. Bost. Soc. Nat. Hist. **8**: 289–306. (1862.)

‖ Proc. Acad. Nat. Sci. Phil. **1863**: 2–25. Proc. Acad. Nat. Sci. Phil. **1865**: 109–133.

¶ Pal. N. Y. 5^1. (1884–1885.)

** Proc. Acad. Nat. Sci. Phil. **1889**: 284. Am. Geol. **5**: 193. (1890.)

on comparisons with the type specimens, and are evidently erroneous in some cases.

In all the work which has been done in the past, on the Kinderhook fossils at Burlington, little or no effort has been made to assign the species to their definite stratigraphic positions in the section. It has usually been deemed sufficient to refer a species to the "Yellow Sandstone, Burlington, Iowa," ignoring the fact that there are two yellow sandstones in the Kinderhook at that place, whose faunas are almost entirely distinct, there being only a small number of species common to the two beds. The fauna of the oolite bed can be more easily recognized from the literature, but even the fossils from this well marked horizon have often been recorded simply as coming from the "Kinderhook beds, Burlington, Iowa."

In the White collection most of the specimens are marked with a number indicating the bed from which they came, and a careful study of that collection supplemented by an examination of the faunas in the field and of material kindly loaned by Prof. Calvin, leads to the recognition of at least four distinct faunal zones in the section in which fossils are abundant, and three other zones in which the fossils are less abundant but which still possess their own faunal characteristics. These seven faunal zones correspond with the seven beds recognized by the writer in the section.

The fauna described in the present paper is that of bed No. 2 (Weller). This is the lower one of the two yellow sandstone horizons, and it contains the most prolific fauna in the whole section. It is characterized by multitudes of individuals of *Chonopectus fischeri* (W. and P.), and for this reason the sandstone will be designated as the Chonopectus sandstone. Usually this bed is a soft, friable, yellow grit or fine sandstone, in which the fossils are always preserved as casts, though in many cases the cavities left after the solution of the shell, have been closed by pressure. At one locality on Flint River, this bed is represented by a highly fossiliferous, much harder, blue sandstone, which has weathered along the joints into a soft yellow rock with characters similar to the usual exposures of the bed. From this occurrence it seems possible that the softness and yellow color of the bed as usually exposed may be due to a weathered condition, but this could only be determined by extensive excavations. The fossils are most abundant, in fact are almost wholly restricted to the upper five or six feet of the bed, just below the thin band of impure limestone,— bed No. 3 (Weller).

It is usually possible to recognize the fossils from the Chonopectus sandstone, by their lithologic characters alone. They could only be confused with those of bed No. 5 (Weller), but the Chonopectus sandstone is usually of a deeper yellow color, often reddish, and is softer than bed No. 5. In the upper yellow sandstone, No. 5, the cavities remaining from the solution of the shells are usually preserved, the greater density of the rock not allowing them to be closed by pressure.

The writer is under the greatest obligation to Prof. I. C. Russell of Ann Arbor, Michigan, for the use of the types and other specimens of Burlington fossils preserved in the "White Collection" in the University of Michigan. These specimens have been loaned for study with the utmost generosity, and without the hearty co-operation of Prof. Russell the present paper could never have been prepared. A large proportion of the illustrations here published have been drawn from the type specimens in the University of Michigan collection.

Prof. Samuel Calvin, state geologist of Iowa, has also loaned a small collection of Kinderhook fossils from Burlington. Acknowledgment is also due Dr. H. F. Bain, assistant state geologist of Iowa, for the helpful encouragement he has given during the prosecution of the work.

Description of Species.*

ECHINODERMATA.

A few detached joints of crinoid stems have been observed in the Chonopectus sandstone, as well as a single form which

* The bibliographic references have been omitted from these descriptions. For these the reader is referred to Bulletin 153, U. S. Geological Survey, "A Bibliographic Index of North American Carboniferous Invertebrates," by Stuart Weller. Washington, 1898. In the case of species referred to a different genus in the present paper than in Bulletin 153, a reference is given to the Bulletin.

seems to be the impression of a crinoid arm, and very imperfect cast of a calyx. None of these fragments can be identified, even generically.

VERMES.

Indefinite worm burrows are sometimes present in the Chonopectus sandstone, but they are usually not conspicuous.

MOLLUSCOIDEA.

BRACHIOPODA.

LINGULA MEMBRANACEA Win.

Pl. I. f. 20.

"Shell flattened, quadrate-elliptical, nearly as broad near the beak as at the same distance from the anterior margin; length nearly equal to twice the width; lateral margins slightly curved; beak scarcely elevated, near the posterior margin, but with a narrow belt behind it. Shell substance membraneous, marked externally by very delicate, regular concentric lines." Length 12 mm., greatest width 8 mm.

Remarks. This species is represented in the University of Michigan collection by the single imperfect type specimen with rather indefinite characters. The above description is a copy of the original one by Winchell. The specimen is imperfect along the margins, and if it were complete the shell would be wider posteriorly than is represented in the illustration.

ORBICULOIDEA CAPAX (White).

Pl. I. f. 19.

"Shell subcircular in outline, dorsal [brachial] valve much convex, apex small, prominent, eccentric, and pointing backwards. Surface having a rather smooth appearance, but marked by fine lines of growth and these crossed by very faint, somewhat distinct, radiating striae."

Remarks. The only specimen of this species which has been observed in the Chonopectus sandstone, is the type preserved in the University of Michigan collection. The specimen is an imperfect, badly crushed example, which when complete must have had a diameter of about 25 mm. Any really distinguishing characters by which it may be separated from various other species of the same genus in the Devonian and Carboniferous faunas, are not well preserved. The description of the species given above is a copy of the original one written by White.

ORTHOTHETES INAEQUALIS (Hall).

Pl. I. f. 18.

Shell subplano-convex or slightly concavo-convex, sub-elliptical or subsemicircular in outline, more or less unsymmetrical; the hinge-line usually equaling the greatest width of the shell, but sometimes a little less. Pedicle valve nearly plane, slightly concave or convex; usually convex near the beak and concave in all directions to the lateral and anterior margins. Brachial valve strongly convex, greatest convexity near the middle. Surface of both valves marked by fine, radiating costae which are somewhat irregular, and often alternate in size. More or less conspicuous concentric lines of growth are often present on one or both valves, though they are usually stronger on the pedicle valve. The dimensions of an average specimen are: length, 19 mm., and breadth, 26 mm.

Remarks. A study of a large number of specimens from many localities and horizons, will probably show this species and perhaps others of the same genus in the lower Carboniferous faunas, to be not distinct from *O. chemungensis* which is so common throughout many of the Devonian faunas. Because of their great amount of variation, it is extremely difficult to draw sharp specific lines between the members of this genus, and this can only be done when a large number of specimens from many localities shall be brought together and diligently studied.

SCHIZOPHORIA SWALLOVI (Hall).

Pl. I. f. 11-13.

Shell subcircular or transversely subelliptical in outline; hinge-line shorter than the greatest width of the shell, the cardinal extremities rounded. Pedicle valve depressed convex near the beak, flattened on the sides, with a broad, shallow, mesial sinus beginning in the middle of the shell and becoming more conspicuous towards the anterior margin; cardinal area of moderate size. Brachial valve somewhat regularly convex or gibbous. Surface marked by fine, closely arranged radiating striae, and by a few indistinct lines of growth. In the internal casts the muscular impressions are well defined. Length 30 mm., breadth 38 mm., convexity of brachial valve 13 mm.

Remarks. For a discussion of the relationship between the later Devonian and the earlier Carboniferous species of the genus *Schizophoria*, the reader is referred to the first of these Kinderhook Faunal Studies.* The Chonopectus sandstone specimens do not materially differ from the Northview specimens, and are more Carboniferous in aspect than Devonian. The small specimen illustrated (Plate I. fig. 13) is the type of Winchell's species *Orthis flava*, and is only an immature example of *Schizophoria swallovi*.

Chonetes illinoisensis Worthen.

Pl. I. f. 14.

Shell of medium size, varying in outline from subelliptical to semielliptical; the hinge line usually a little shorter than the greatest width of the shell, and the cardinal extremities slightly rounded. Pedicle valve rather strongly convex in the middle, flattened towards the cardinal extremities; the cardinal margin furnished with five or six oblique spines on each side of the beak. Brachial valve slightly concave, the concavity much less than the convexing of the opposite valve. Surface of both valves marked with from 120 to 200 fine, rounded, dichotomizing striae. The dimensions of an average specimen are: length 10 mm. and breadth 13 mm.

Remarks. The type specimens of *Chonetes multicosta* Win., should be in the University of Michigan collection, but they cannot now be found. The species is said to range all through the Kinderhook and into the base of the Burlington limestone at Burlington, Iowa. It most nearly resembles *C. illinoisensis*,

* Trans. St. Louis Acad. Sci. **9**: 13.

being distinguished from that species chiefly by reason of its greater number of radiating striae. In all the collections of Chonopectus sandstone fossils which have been studied in connection with the present investigation, three species of *Chonetes* have been observed, but only one of these resembles in any degree the description of *C. multicosta.* From a careful study of the best of these, and comparison with many specimens of *C. illinoisensis* from the Osage fauna, there seems to be no reason for believing them to be distinct from *C. illinoisensis.* For the present, therefore, it seems best to consider *C. multicosta* as a synonym of *C. illinoisensis* though if the type specimens are found at some future time it may be found to be distinct. In none of the Chonopectus sandstone specimens have the spines been observed, and the specimens themselves are for the most part imperfect.

CHONETES sp. — Cf. C. GENICULATA White.

Pl. I. f. 16.

Shell more or less subelliptical in outline, with the hinge-line usually a little shorter than the greatest width of the shell. The pedicle valve strongly convex in the middle, slightly flattened near the cardinal extremities; three or four oblique spines present along the cardinal margin on each side of the beak. The concavity of the brachial valve much less than the convexity of the pedicle valve, in some individuals it being nearly flat throughout. Surface of each valve marked by eighty to one hundred fine radiating striae. Dimensions of an average specimen: length 5 mm., width 7 mm.

Remarks. *C. geniculata*, with which this species may be compared, occurs in abundance in the Louisiana limestone at Louisiana, Missouri, and many specimens from that locality have been examined. The Burlington specimens agree closely with those from Louisiana in general form, but their average size is a little greater, and the radiating striae with which they are marked are much finer, there being only about forty-five or fifty in *C. geniculata*. In the list of localities for *C. geniculata*, given by White with his original description, Burlington, Iowa, is recorded with a query, and it was undoubtedly the little shell here described that he had in mind, because of its abundance at Burlington in the Chonopectus sandstone, and especially in the thin limestone band which lies just above the sandstone. This limestone band which is only a few inches in thickness is usually constituted almost wholly of the shells of this single species. Upon the internal casts of the pedicle valve in the Chonopectus sandstone, such as the one here illustrated, the radiating striae can usually not be recognized, hence their absence from the figure.

CHONETES sp. undet.

Pl. I. f. 15.

A few imperfect specimens of a third species of *Chonetes*, not yet identified with any described form and intermediate in size between the other two, have been found in the Chonopectus sandstone. It differs from either of its associates in its coarser radiating striae, there being only 40–50 on each valve. The shell is also much more extended along the hinge-line, the cardinal extremities being acutely angular. The species somewhat resembles *C. ornatus* from the Louisiana limestone at Louisiana, Missouri, but the striae are finer and the cardinal extremities more acute than in that species. The best specimen observed is an impression of the outside of the brachial valve which is moderately convex in the middle and flattened towards the cardinal extremities. The contour of the pedicle valve is not certainly known.

CHONOPECTUS FISCHERI (N. & P.).

Pl. I. f. 17.

Shell semi-elliptical in outline, the hinge-line equal to or a little less than the width of a shell. Pedicle valve convex, somewhat gibbous in the middle, often nearly flat at the umbo and along the hinge-line, compressed at the cardinal angles; the hinge-line furnished with five to seven nearly straight tubular spines on each side of the beak, those nearest the beak usually being at right angles to the hinge-line while the outer ones are slightly oblique. Brachial valve moderately concave, following the curvature of the opposite valve. Surface marked by fine radiating striae, by concentric lines or wrinkles of growth which are most prominent near the hinge-line, and by a double set of curved, diagonal lines. The dimensions of an average specimen are: length, 16 mm., breadth, 21 mm., and convexity, 4½ mm.

Remarks. This species is by far the most abundant in the Chonopectus sandstone. Not a fragment of the rock in the fossiliferous layers can be broken without exposing one or more specimens of this species, and the number of individuals present is many times that of other species in the fauna. As they occur in the sandstone, the surface markings are usually obliterated to a very great extent so that they appear to be nearly smooth, but the concentric lines or wrinkles of growth may usually be observed near the hinge-line, and also the curved diagonal lines.

PRODUCTUS SEMIRETICULATUS Martin.

Pl. I. f. 5–6.

A detailed description of this cosmopolitan species is not necessary. The specimens in the Chonopectus sandstone resemble *P. burlingtonensis* Hall, of the Burlington limestone, but they are constantly less convex than that species. In size and in general characteristics, aside from the convexity, these specimens approximate *P. burlingtonensis*, and it is possible that they should be considered as constituting a variety of that species. It is difficult as yet, if not altogether impossible, to draw sharply defined specific lines in the genus *Productus*, and therefore it is thought best for the present to refer the Chonopectus sandstone specimens to the more general species *P. semireticulatus*, which as understood at present includes a great variety of forms. The specimen illustrated in the accompanying figures 5 and 6 is the one referred to by Winchell* as *P. martini*, and the one in figures 7 and 8 is one of the types of *P. curtirostris* Win.† This latter species proves to be nothing more than the external impression of the brachial valve of *P. semireticulatus*, and the name therefore becomes a synonym.

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* Proc. Acad. Nat. Sci. Phil. **1863 : 4.**

† Proc. Acad. Nat. Sci. Phil. **1865 : 114.**

PRODUCTUS COOPERENSIS Swall.?

Pl. I. f. 3–4.

The specimens in the University of Michigan collection, referred by Winchell to this species, differ from *P. semireticulatus* chiefly in the nearly obsolete radiating plications. The specimens are also more gibbous than those that are more completely plicated. Associated with these specimens there are others which are intermediate in their characters between the two forms, and it is not improbable that both those referred to *P. cooperensis* and to *P. semireticulatus* are members of a single variable species. The original *P. cooperensis* was described from the Chouteau limestone of Cooper County, Missouri. It has never been illustrated and the identity of these Burlington specimens with it is by no means certain.

PRODUCTUS LAEVICOSTUS White.

Pl. I. f. 1–2.

This species, first described from the Burlington limestone at Burlington, Iowa, is a member of the group of species of *Productus* typified by *P. cora*. All the species of this group are characterized by their fine, dividing, more or less wavy, radiating costae, and by the conspicuous transverse wrinkles of the shell in the region of the cardinal extremities. *P. laevicostus* is closely related to the typical *P. cora* as it occurs in the Coal Measure faunas, but the beak is always much more pointed than in the latter species, and it is also more free from spines.

PRODUCTELLA NUMMULARIS (Win.).

Pl. I. f. 9–10.

Strophalosia nummularis, Bull. U. S. G. S. 153 : 613.

Shell subcircular in outline, truncated by the hinge-line; hinge-line shorter than the greatest width of the shell. Pedicle valve depressed convex, most prominent at a point a little in front of the beak, decidedly flattened on each side of the beak towards the cardinal extremities; the beak, rather small and pointed, incurved, projecting but slightly beyond the hinge-line. Brachial valve discoid, with a broad, shallow mesial depression which is bounded on the two sides by lines diverging from the beak nearly at right angles to each other; beak depressed; the cardinal process, as shown in casts of the inside of the valve, is small, bifid, and lies in the plane of the valve projecting beyond the hinge-line; the internal casts also show a low median ridge extending from near the beak almost to the middle of the shell; there are also two low, widely diverging socket plates whose impressions are preserved in casts of the brachial valve. The surface of the pedicle valve is covered with innumerable fine spines which attain a length of at least 5 mm. The brachial valve also is marked by small pits which may represent a covering of spines, though the spines themselves have not been observed. Both valves are marked by more or less conspicuous concentric lines of growth. The dimensions of the best preserved pedicle valve observed, one of the type specimens, are: length, 20 mm., breadth, 22 mm., thickness, 3½ mm. The largest specimen preserved is a brachial valve whose length is 22 mm. and breadth, 32 mm.

Remarks. This species was referred to the genus *Strophalosia* by Winchell in his original description, but it is undoubtedly a *Productella*. The fine spines covering the surface are usually destroyed, leaving only a pitted surface, but in a single specimen of a pedicle valve in the University of Chicago collection, their presence is clearly shown. The species resembles in some degree *P. pyxidata* from the Louisiana Limestone at Louisiana, Missouri, but it is a more nearly circular shell and often attains a much greater size.

PUGNAX STRIATOCOSTATA (M. and W.) var.?

Pl. II. f. 16–17.

Shell much wider than long, broadly subtriangular in outline, the angle of divergence of the lateral margins from the beak 110° to 113°. Pedicle valve depressed convex with a broad, deep, sharply defined mesial sinus which is greatly produced anteriorly in a lingual extension nearly at right angles to the plane of the valve. Brachial valve extremely gibbous, the mesial fold strongly elevated in front. Surface of the shell marked by simple, strong, subangular plications, of which there are usually four on each side of the mesial sinus in the pedicle valve, and three on each side of the fold of the brachial valve; in the fold and sinus the number of plications varies from two to four in the sinus with always one more on the fold. In addition to the plications both valves are marked over their entire surface by fine radiating striae which are often nearly obsolete in the casts. The dimensions of an average specimen are: length, 22 mm., breadth, 30 mm., thickness, 22 mm.

Remarks. In 1855 Shumard * described *Rhynchonella missouriensis* from the Chouteau limestone of Cooper and Boone Counties, Missouri. In 1868 Meek and Worthen † described a shell from Kinderhook, Pike County, Illinois, as the same species, but in their remarks on the species they pointed out that Shumard included what they considered to be two distinct species in *R. missouriensis.* Their own specimens they identified with the larger form of Shumard's species and suggest the name *striatocostata* for it, retaining the original name *missouriensis* for Shumard's smaller form. One of the most conspicuous features of Meek and Worthen's *R. striatocostata* are the fine radiating striae which cover the entire surface of both valves in addition to the strong plications. Shumard mentioned no such markings in his description of *R. missouriensis*, but did mention fine, concentric lines of growth, and in some specimens from the Chouteau limestone at Sedalia, Missouri, believed to be *R. missouriensis*, there are no signs of radiating striae but the fine concentric lines of growth are finely shown. From a study of the specimens, therefore, it seems that Meek and Worthen were mistaken in identifying their shell from Kinderhook, Illinois, with Shumard's, whether the latter really includes two distinct species or only one. All of these shells were originally described as members of the genus *Rhynchonella*, but they are now referred to *Pugnax.*

In the Kinderhook formations at Burlington, there are two varieties or perhaps distinct species characterized by the fine radiating striae of *P. striatocostata.* One of these occurs in the limestone above the Chonopectus sandstone and may be certainly identified with Meek and Worthen's shell from Kin-

* I and II Rep. Geol. Mo. 204.

† Geol. Surv. Ill. 3 : 450.

derhook, Illinois. The second form occurs in the Chonopectus sandstone, and apparently presents constant characters by which it may be separated from the shell in the limestone above. It is always larger and thicker than the typical *P. striatocostata*, and as they diverge from the beak the lateral margins form a wider angle than in the limestone specimens. The differences are so great and apparently so constant that it is possible that the Chonopectus sandstone form should be given a specific designation, but for the present it will be considered only as a variety. In volume eight of the New York Paleontology this shell is illustrated on plate 62, figs. 44–45, under the name *P. missouriensis*, while the typical form of *P. striatocostata* is illustrated under the same name on plate 60, figs. 33–34. Allied species have been described from the Waverly sandstone in Pennsylvania.

RHYNCHONELLA sp. undet.

Pl. II. f. 4–5.

Several specimens of *Rhynchonella* have been observed in the fauna of the Chonopectus sandstone, but they are too imperfect for certain identification. They seem to belong to a single variable species, the two figures given representing the extremes, one with an obtuse and the other with an acute beak. The umbonal region of the pedicle valve is convex, the sinus being present only towards the anterior margin of the shell, and there it is very shallow. The anterior margin of the valve is abruptly incurved so that the margin lies nearly at a right angle to the general plane of the shell. The surface of each valve is marked by about twelve or fourteen simple rounded plications. Most of the specimens observed are pedicle valves, only a few fragments of the brachial valve having been seen.

EUMETRIA ALTIROSTRIS (White).

Pl. II. f. 18–19.

Shell longitudinally subovate in outline, the valves nearly equally convex. Brachial valve with a prominent, elevated beak slightly incurved at the tip, and perforated by a large circular foramen; mesial sinus shallow, ill-defined. Brachial valve without an appreciable mesial fold. Surface of each valve marked by twenty or twenty-two prominent, simple, rounded plications, which gradually increase in size towards the front; the furrows between the ribs much narrower than the ribs themselves; the groove along the median line of the pedicle valve stronger than any of those on either side. Length of an average specimen 19 mm., breadth, 15 mm., and thickness, 10 mm.

Remarks. The types of this species in the University of Michigan collection are four in number, all of them more or less imperfect. The specimen here illustrated is a more perfect one in the University of Chicago collection from the same locality as the types. The species resembles *E. marcyi* (Shum.) from the St. Louis limestone fauna, but it has a more acute and more erect beak, coarser plications, and the slight median sinus with its stronger median furrow.

Athyris corpulenta (Win.).

Pl. II. f. 12–15.

Shell varying from longitudinally subelliptical to subcircular in outline, the valves becoming exceedingly gibbous in the adult individuals. Pedicle valve gibbous in the middle, usually with a shallow, ill-defined mesial sinus in the anterior half of large shells, though this is sometimes practically obsolete; in those specimens with the sinus well developed, the anterior margin of the valve is produced; the beak is small and incurved over that of the brachial valve. Brachial valve nearly as convex as the pedicle valve so that the older and shorter individuals become subglobular in form; the specimens with a sinus developed in the pedicle valve have a corresponding, ill-defined fold in the brachial valve. Surface of both valves marked by strong, concentric lines of growth which are often crowded near the margin. The dimensions of a small, exceedingly elongate specimen are: length, 15 mm., breadth, 11 mm., and thickness, 10 mm.; those of another larger and very gibbous specimen are: length, 16 mm., breadth, 18 mm., thickness, 20 mm. This latter specimen has apparantly been somewhat distorted so that the convexity of the pedicle valve is too great and consequently also the thickness of the entire shell.

Remarks. The general aspect of the type specimens of this species is remarkable. The great gibbosity of the larger specimen illustrated, causes the lateral slopes of the two valves to lie in the same general plane, so that the sides of the shell present a regular convexity. The gibbosity of the pedicle valve of this specimen is accentuated by the crushing of the anterior portion of the valve. The smaller specimen illustrated perhaps represents more nearly the normal form of the species, though this one is extremely elongate, the average form of the species being that in which the length and the breadth are nearly equal. It is by no means certain that this species belongs to the genus *Athyris*, but it was originally described as *Spirigera*, a synonym of *Athyris*, and it is therefore allowed to remain here until its generic relations can be accurately determined.

Spirifer subrotundatus Hall.

Pl. II. f. 8–10.

Shell subcircular in outline, the hinge-line much shorter than the width of the shell. Pedicle valve rather strongly convex, the umbo large and prominent; the beak moderately incurved; the cardinal area rather high, concave, extending to the ends of the hinge-line; the mesial sinus shallow, rounded, not sharply defined. Brachial valve less convex than the opposite one, its greatest convexity posterior to the middle, from which point it curves regularly to the lateral and anterior margins; the mesial fold not sharply defined and scarcely elevated above the general surface of the valve. Surface of each valve, both the lateral slopes and the fold and sinus, covered with from sixty to seventy-five bifurcating plications, and by more or less conspicuous concentric lines or wrinkles of growth. The dimensions of an average specimen are; length, 32 mm., breadth, 37 mm., and thickness, 19 mm. The largest specimen observed is 43 mm. long and 48 mm. broad.

Remarks. This species is one of the commoner ones in the Chonopectus sandstone. It belongs to a decidedly Carboniferous type of the genus in which the shells are completely covered with bifurcating plications. In this respect it is allied to *S. grimesi* H., of the Osage fauna, and may possibly be considered as a genetic predecessor of that species. It never grows so large as *S. grimesi*, however, and has a shorter hinge-line. It is not known whether the shell is marked by the very fine radiating striae which characterize *S. grimesi*.

SPIRIFER BIPLICATUS Hall.

Pl. II. f. 6–7.

Shell, exclusive of the cardinal extensions, semicircular or semielliptical in outline; the hinge-line greatly extended in long mucronate points. Pedicle valve with a rather small incurved beak and a prominent umbo; the cardinal area narrow; the slope to the cardinal margin rather steep, that to the cardinal angles and lateral margins slightly concave; the mesial sinus narrow and shallow, marked in the center by a single, simple plication, the two bounding plications larger than any of those on the lateral slopes. Convexity of the brachial valve about equal to that of the pedicle valve, the mesial fold narrow, not elevated above the general surface of the valve, marked along its median line by a simple, shallow furrow, the bounding furrows deeper than those on the lateral slopes. Surface of each valve marked by about twelve simple plications on each lateral slope which grow smaller as they approach the cardinal angles, and by concentric lines of growth. The dimensions of an average specimen are: length, 9 mm., breadth along the hinge-line, 50 mm., thickness, 8 mm.

Remarks. This species is remarkable because of its greatly extended, mucronate cardinal extremities. In this respect it strongly simulates some Devonian species such as *S. pennatus* Atw., and has no near allies in the succeeding Carboniferous faunas. We have then, associated in this fauna, this strictly Devonian type of the genus *Spirifer*, and a characteristic Carboniferous type represented by *S. subrotundatus*.

SYRINGOTHYRIS EXTENUATUS (Hall).

Pl. I. f. 1–3.

Shell subsemielliptical in outline, greatly extended along the hinge-line. Pedicle valve subpyramidal; the cardinal area high, flat or slightly convex or concave, sharply defined along the margin, sloping forward from the hinge-line at an angle of about 30° with the plane of the valve; the mesial sinus broad and deep, not plicated, rounded in the bottom, not sharply defined, produced anteriorly in a lingual extension; the lateral slopes very narrow; in the sandstone casts the syrinx is usually well exhibited. Brachial valve somewhat gibbous in the middle, the lateral slopes concave from the deepest point of the valve to the cardinal extremities, flattened towards the cardinal angles; the mesial fold prominent, rounded above, sharply defined, not plicated, deeply emarginate in front. Surface of each valve marked with fifteen to twenty simple rounded plications on each lateral slope, growing smaller towards the cardinal extremities; in addition to the plications each valve is usually marked by several more or less conspicuous lines of growth which in the pedicle valve are continuous across the cardinal area. The dimensions of an average specimen are: length, from beak of brachial valve to the anterior margin of the fold and sinus, 14 mm., length of hinge-line, 41 mm., height of cardinal area, 15 mm. Another large brachial valve has a length of 17 mm., and a breadth along the hinge-line of 63 mm.

Remarks. It has always been found difficult to draw sharply defined specific lines between the species of the genus *Syringothyris.* From the Kinderhook beds at Burlington two species of the genus have been described, *S. extenuatus* Hall, and *S. halli* Winchell. Hall's species is from the Chonopectus sandstone; it was originally described from the brachial valve alone, but in recent collections from Burlington several specimens preserving both valves have been secured and it is a common species in the fauna. The types of *S. halli* are not from the Chonopectus sandstone but from the overlying limestone, although specimens of *S. extenuatus* from the sandstone are present in the University of Michigan collection labeled *S. halli* var., by Winchell. From a careful study of the types of *S. halli* and of a good collection of *S. extenuatus*, it is believed that the two species are not identical as has been sometimes suggested. As they occur at Burlington *S. halli* is always smaller than *S. extenuatus*, the largest specimen of the former being 36 mm. in extent along the hinge-line, while the largest specimen of the latter is 63 mm. The cardinal area of *S. extenuatus* is usually perfectly flat or slightly convex, in but one specimen is it slightly concave, while in *S. halli* on the other hand, the area is usually concave at least towards the beak, and in some individuals it is strongly concave throughout the entire height. The most important difference between the two species, however, is to be found in the length of the pedicle valve from the beak to the anterior margin. In *S. extenuatus* this distance is always shorter than the height of the area, while in *S. halli* it is always

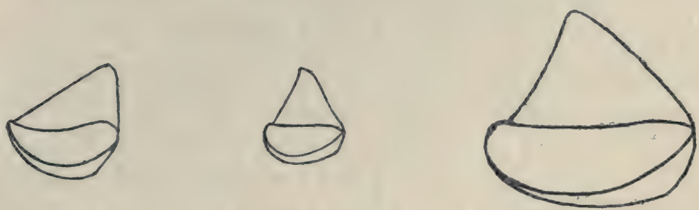

Fig. 1. Fig. 2. Fig. 3.

EXPLANATION OF FIGURES.

Profile views of:—1. *Syringothyris extenuatus* from the Chonopectus sandstone. 2. One of the type specimens of *S. halli* from Burlington. 3. *S. hannibalensis* from the Louisiana limestone at Louisiana, Mo. These outlines show the variation in the angle of forward slope of the cardinal area.

longer. Perhaps a better manner of expressing this same difference is in the angle of forward slope from the hinge-line of the area of the pedicle valve. In the measurement of this angle the plane of the pedicle valve is assumed to pass through the hinge-line and the lateral margins of the valve, cutting off the anterior extension of the mesial sinus. While these lines do not exactly locate a plane, they do so approximately, and the angle between this plane and the cardinal area may be approximately measured. In nine specimens of *S. extenuatus* this angle does not vary more than two or three degrees from 30°, while in the two type specimens of *S. halli* perfectly enough preserved to admit of measurements, this angle varies only two or three degrees from 60°. In five specimens of *S. hannibalensis* Swallow, from the Louisiana limestone at

Louisiana, Missouri,* varying greatly in other characters, such as length, breadth, thickness, curvature of the area and length of hinge-line, this angle remains approximately the same, being not far from 60°. If the size of this angle may be considered as a specific character of value, then *S. extenuatus* is certainly a good species while *S. halli* may be only a small variety of *S. hannibalensis.* Schuchert and others have considered *S. hannibalensis* as identical with *S. Carteri* Hall, and it is quite possible that this is true, but it is certainly a mistake to consider *S. halli* as a synonym of *S. extenuatus.*

RETICULARIA COOPERENSIS (Swall.).

Pl. II. f. 11.

Shell transversely subelliptical in outline, the hinge-line very short, the cardinal angles rounded. Pedicle valve rather strongly convex, the greatest convexity between the middle of the valve and the beak; the beak moderately acute, incurved; the cardinal area small, a large portion of it occupied by the delthyrium, its margins rounded; mesial sinus shallow, undefined, sometimes almost obsolete. Brachial valve less convex than the opposite one, its greatest convexity at or a little posterior to the middle; the mesial fold ill-defined, not elevated above the general surface of the valve. Surface marked by more or less conspicuous concentric lines of growth, and also by very fine radiating costae which form little pustules at the margins of the concentric ridges, indicating the presence of concentric rows of fine spines upon the surface of the shell. Dimensions of a rather large specimen: length of brachial valve, 18 mm., breadth, 25 mm.

Remarks. The types of *R. hirta* (W. and W.) are from the "Yellow sandstone" at Burlington, but apparently from the upper formation included under this name. In the Chonopectus sandstone the species is not common, the brachial valve illustrated being the only one certainly identified from that formation. *R. hirta* is generally considered as synonymous with *R. cooperensis* (Swall.) from the Chouteau lime-

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* These specimens were generously loaned for study by Mr. R. R. Rowley of Louisiana.

stone of Cooper County, Missouri, and as Swallow's name has priority it is here adopted. It is possible that both these names should be considered as synonymous with *R. lineata* (Martin), but this can be certainly determined only when a large number of specimens can be compared. These sandstone specimens are, of course, all casts and consequently the surface markings of the shells are indistinct, the concentric lines usually being the only ones that can be definitely recognized.

BRYOZOA.

Impressions of bryozoa belonging to *Fenestella* or some allied genus are not uncommon in the Chonopectus sandstone, but the state of their preservation is not such as to admit of their identification.

MOLLUSCA.

PELECYPODA.

Aviculopecten tenuicostus Win.

Pl. III. f. 3.

"Shell small, equilateral; pallial margin circularly rounded between anterior and posterior extremities, which lie midway between the beak and the opposite side. Beak slightly prominent; body of shell bounded by a truncation from beak to each lateral margin; anterior truncation slightly concave. Anterior wing of left valve moderately inflated, as long as anterior side of shell, distinctly rounded at extremity, joining hinge-line by a rounded angle, and separated from body of shell by a broadly V-shaped sinus, rounded at the bottom. Posterior wing only very imperfectly seen. Surface (of left valve) ornamented by fine, rigid, nearly equidistant ribs, 50 or 60 in number, separated by concave intervals; similar but finer ribs or striae marking the anterior ear. Frequently from three to five equidistant costate elevations appear, each of which bears two or three of the ribs. A few inequidistant concentric lines are seen. Right valve unknown."

Remarks. The types of this species consist of seven specimens, and it is rather singular that in each of these the posterior ear has been destroyed so that its form cannot be determined. The specimen illustrated is the best preserved and largest one of the types, having a height and length of 13 mm. each. The smallest of the type specimens is but 8 mm. in height, while a fragmentary specimen not included among the types is 17 mm. in height. The most characteristic features of the species are the fine radiating striae with the variable number of raised ribs, each of which is covered with striae similar to those between. These ribs are variable in number, from three to six or seven. In some specimens they are much more conspicuous than in others, and those near the center of the shell are always most conspicuous. Sometimes the ribs are nearly obsolete.

AVICULOPECTEN CAROLI Win.

Pl. III. f. 4.

Shell subcircular, the height and length each 25 mm., nearly equilateral, the greatest convexity 6 mm. at a point a little above the middle. Hinge-line shorter than the shell. Beak central, scarcely elevated above the hinge-line. Anterior ear of the left valve slightly convex, sharply depressed from the body of the shell; its anterior margin nearly straight above and forming approximately a right angle with the hinge-line, rounded below where it forms a shallow angular notch with the margin of the shell below. Posterior ear of the same valve not so sharply separated from the body of the shell; its posterior extremity acutely angular, and the posterior margin forming with the margin of the shell below a shallow, rounded notch. The anterior, basal and posterior margins together form something more than a nearly perfect semicircular curve. Surface of the shell marked by about seventy-five raised costae towards the margin, which vary greatly in size. These costae increase in number by division and by intercalation, so that the number is much less towards the beak. The larger costae are from three to five times the width of the smaller ones. The larger ribs produced into spines on the margin of the shell. The surface is also marked by indefinite concentric lines of growth. The surface markings on the anterior ear become nearly obsolete, while on the posterior ear the concentric markings become stronger at the expense of the radiating costae.

Remarks. The specimens which are labeled as the types of this species in the University of Michigan collection are four in number, two of them being from the Chonopectus sandtone, the others from a higher horizon. It is altogether probable that all these specimens do not belong to a single species, and it is impossible to determine from his description and measurements which one of these specimens Winchell considered as the type. The two species from the Chonopectus sandstone are of the same species, and one of these is here selected to represent the species and the description has been entirely rewritten.

The specimens from the Waverly series in Ohio, identified as *A. caroli* by Hall and by Herrick, probably do not belong to this species.

Pterinopecten. — Cf. P. laetus H.

Pl. III. f. 1–2.

Shell $27\frac{1}{2}$ mm. in height, the length about one-fourth greater than the height. Left valve moderately convex; hinge-line straight, about equal to the greatest length of the shell; pallial margin regularly rounded. Beak scarcely elevated above the hinge-line, located about $\frac{2}{5}$ of the distance from the anterior extremity. The anterior ear of the left valve depressed, slightly convex, separated from the body of the shell by a shallow and narrow sinus; its anterior margin rounded above and nearly straight below, meeting the hinge-line at approximately a right angle, joining the pallial margin in a broadly rounded notch. The posterior wing broad and flattened toward the margin, but not sharply separated from the body of the shell; its posterior margin sinuate. The surface of the left valve ornamented with 85–90 rounded, radiating costae, a few of which near the center of the basal margin are smaller than the others and do not extend to the beak. The costae on the anterior ear are finer than those on the body of the shell, and in the sinus separating the ear from the body of the shell they are nearly obsolete. The costae also grow smaller in size posteriorly, the largest ones being near the center of the basal margin. In addition to the costae the shell is marked with fine concentric lines and with a few coarser lines or indistinct wrinkles of growth.

Remarks. White and Whitfield's description of *Aviculopecten nodocostatus* (= *Pterinopecten nodocostatus*) was based upon two type specimens which are now preserved in the paleontologic collection of the University of Michigan. One of these specimens is a left valve from the Chonopectus sandstone, and the other is a right valve from the upper horizon of the "Yellow sandstone." These two specimens apparently belong to distinct species. The original description agrees in the main with the latter one of the two specimens and it will be retained as the type of the species. The specimen from the Chonopectus bed differs from *P. nodocostatus* in its greater proportionate height, in having nearly twice the number of radiating costae, and in lacking the conspicuous nodosity of the costae from which the specific name *nodocostatus* was taken. There are other differences in convexity, etc., due to the fact that the two specimens are opposite valves.

Except in size the specimen from the Chonopectus bed agrees quite closely with the illustration of *P. laetus* Hall * but is proportionately a little shorter. In general form it agrees even more closely with *P. dignatus* Hall,† but not so closely in its surface markings. Each of these New York species, however, which may in reality be but one, is only about one-half the size of the Burlington specimen. The difference in size, however, can scarcely be taken as a good specific character, and the Burlington specimen is provisionally referred to *P. laetus*. This species was first described from the Marcellus shale of the Hamilton series in New York. At a later date a shell from the Waverly series of Ohio was identified with it by Herrick, but in all respects except size, the Burlington shell agrees more closely with the New York illustration, than does the Ohio specimen illustrated by Herrick.

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* Pal. N. Y. 5^1. *pl. 1. f. 13.*

† Loc. cit. *pl. 1. f. 14.*

PERNOPECTEN ?? sp.

Plate III. f. 5.

It is by no means certain that this genus occurs in the fauna of the Chonopectus sandstone. The specimen here illustrated resembles it in being a nearly flat, smooth shell, but it differs from *Pernopecten* in the absence of both the anterior and posterior auriculations. It is of course possible that the ears have been destroyed, but the margin of the shell seems to be uninjured, and if this is the case it cannot be *Pernopecten*. It is perhaps more probable that this shell should be associated with those called *Posidonomya ? ambigua* by Winchell. (See p. 105, *pl. IV., f. 18, 19.*)

LEIOPTERIA SPINALATA (Win.).

Pl. III. f. 8–9.

Pterinea spinalata. Bull. U. S. G. S. No. 153: 511.

"Shell rather large, very oblique, becoming distinctly arcuate upwards. Left valve very ventricose, with a tapering incurved beak, closely approximated to its fellow; body of valve regularly arched along the umbonal slope, from which line it describes a rapid convexity to the anterior margin, sloping more gradually to the ventral margin and becoming gradually flattened toward the posterior ventral angle. The upper boundary of the body is an abrupt descent to the plane of the posterior wing, and sharply divides the two; posterior wing sloping to the dorsal and posterior borders of the valve, produced above into a slender spine, nearly as long as the posterior end of the shell, with a deep sinuation below. Anterior ear short, saccate, less distinctly divided from the body of the valve. Hinge-line straight, with a long, posterior cartilage facet. Surface marked by irregular wrinkles of growth which become fine striae on the posterior wing, and sharp plications on the anterior slope and auriculation. Right valve smoother and considerably less ventricose, with the posterior wing-surface divided from the body of the valve only by a slight groove."

Remarks. None of the specimens in the University of Michigan collection are marked as types, but there are five well preserved left valves and four right valves of the species, labeled by Winchell, which agree well with his description and which are without doubt good representatives of the species. These specimens exhibit some variation in size and form. The largest one measures 40 mm. from the beak to the farthest posterior extension of the body of the shell, while the same measurement in the smallest shell is scarcely 10 mm. The specimens illustrated are intermediate in size. There is also some variation in the width of the body of the shell, and also in the posterior extension of the wing. In some individuals the posterior angle of the wing reaches nearly as far as the most posterior extension of the body of the shell, while in others it is considerably shorter.

This species has previously been referred to the genera *Avicula* and *Pterinea*, but an examination of authentic specimens shows that the species should be placed in the genus *Leiopteria*. This species differs from the Devonian species of the genus generally, in its greater obliquity and in its narrower shell. *L. speciosa* M. and G. from the Chouteau limestone near Sedalia, Missouri, closely resembles the Burlington species and may be identical with it.

Avicula strigosa (White).

Pl. III. f. 10.

Pterinea strigosa. Bull. U. S. G. S. No. 153: 511.

Shell very oblique, length, 30 mm., greatest height, 8 mm. Hinge-line slightly more than one-half the length of the shell. Anterior and posterior extremities sharply rounded; ventral margin convex; dorsal margin, exclusive of the wing, concave with the concavity less than the convexity of the ventral margin. Beak placed near the anterior extremity of the shell. Behind the beak there is a small, narrow, abruptly compressed wing whose posterior extremity seems to be pointed. Body of the shell very convex, the slope toward the dorsal margin being much steeper than the ventral slope. The greatest convexity at about one-third the length of the shell from the anterior extremity. The anterior extremity forms a small, inflated ear which is separated from the body of the shell by an oblique depression. Surface marked by a few concentric wrinkles which are more conspicuous anteriorly.

Remarks. The form of the posterior wing of this species is not distinctly shown in the type specimen, but it is believed to be as shown in the illustration. In the original description this wing is not mentioned, it not having been uncovered in the type specimen at that time. The species was originally described as *Gervillia strigosa* and it has since been referred to the genus *Pterinea*, though it is much more oblique than any other species referred to that genus. So far as its characters are preserved, it seems to be cogeneric with the Coal Measure species *Avicula longa*, and it is therefore placed in the genus *Avicula* although its hinge characters have not been preserved.

PTERONITES WHITEI (Win.).

Pl. III. f. 6-7.

Avicula whitei. Bull. U. S. G. S. No. 153: 106.

" Shell large, transverse, exceedingly oblique, with nearly terminal beaks. Hinge-line more than three times the greatest dorso-ventral dimensions. Anterior ear pouched, not distinctly divided from the body of the shell. Left valve ventricose; umbonal ridge somewhat arcuate, or nearly straight, forming an angle of about 20° with the hinge-line; slope thence to the ventral margin very rapid — to the dorsal side rather gradual and symmetrical to the very hinge-line — the posterior wing not being divided from the body of the shell. Ventral margin, in the middle rather straight and nearly parallel with the dorsal; posterior margin sigmoidal by a deep, or rather shallow sinus, isolating the posterior end of the cartilage plate from the body of the shell; posterior wing triangular, exceeding the shell. External surface marked by numerous fine, irregular striae of growth. Right valve much less ventricose, marked on the body and anterior slope by numerous sharp, regular raised concentric striae which become very faint posteriorly. Cardinal line in each valve with a long, slender, bifid lateral tooth behind the beak."

" Length of dorsal side, 53 mm.; greatest dorso-ventral dimensions, 17½ mm.; depth of left valve, 5½ mm."

Remarks. The specimens in the University of Michigan collection which are labeled as types of this species are ten in number, but of all these only two left valves approach perfection in their condition of preservation. Judging from Winchell's measurements it is the larger one of these two which is really the type of the species. Most of the specimens are smaller than this one, some of them having a length no greater than 15 mm.

The species approaches more closely to *P. profundus* Hall, from the Chemung fauna of New York, than any other species of the genus, but the two are quite distinct. *P. whitei* is a much narrower shell and lacks the pointed anterior ear of *P. profundus.*

Mytilarca occidentalis (W. & W.).

Pl. III. f. 11.

Shell elongate, narrowly ovate; length, 52 mm., breadth, 20 mm. Hinge-line short; ventral margin gently curving from just below the beaks to the abruptly rounded posterior margin; dorsal margin gently curving to the posterior extremity of the short hinge-line. Beaks acute, situated at the extreme anterior end of the shell; valves convex in the posterior part, becoming gibbous anteriorly, the greatest convexity anterior to the middle; the umbonal region narrow and the convexity continued along the median line to the posterior extremity of the shell. Surface marked by fine, more or less irregular concentric striae, and at irregular intervals by stronger concentric wrinkles.

Remarks. The specimen here illustrated is the type of the species. It is somewhat compressed dorso-ventrally, so that it is proportionately narrower than before this distortion took place, and the convexity along the median line is proportionately accentuated. Hall's* illustration of the species was drawn from the same specimen, but that figure is made to represent the shell as restored to its normal form.

Mytilarca fibristriata (W. & W.).

Pl. III. f. 12.

Shell elongate, ovate, very oblique; length, 41 mm., breadth, 16 mm. Hinge-line short; ventral margin nearly straight in the central portion, curving gently upward to the

* Pal. N. Y. 5[1]. *pl. 87. f. 11.*

anterior extremity of the hinge-line in front, and posteriorly curving into the somewhat abruptly rounded posterior margin; dorsal margin gently curved to the extremity of the hinge-line. Beaks acute, suberect, situated at the extreme anterior end of the shell. Valves moderately convex in the posterior part, becoming gibbous anteriorly. The line of greatest convexity near the ventral side of the shell, the ventral slope being very steep and the dorsal slope more gentle. Surface marked by fine radiating striae, and by more or less inconspicuous lines of growth.

Remarks. This species differs from the last in the presence of the radiating striae and in the more ventral position of the line of greatest convexity.

GONIOPHORA JENNAE (Win.).

Pl. III. f. 13–14.

Isocardia jennae. Bull U. S. G. S. No. 153: 314.

The specimens of this species in the University of Michigan collection labled "types (in part)" are three in number, but the specimen from which Winchell took the measurements given in his original description, is missing, none of those observed being as large as that one. The largest and best of the specimens studied will therefore be selected as the type.

Shell very oblique, the beak at or near the anterior extremity. Dimensions, 26 mm. from the beak to the posterior basal angle, hinge line 14 mm. in length, greatest width from the posterior extremity of the hinge-line to the middle of the ventral margin 14 mm. Hinge-line straight. The posterior margin truncated, meeting the hinge-line in an obtuse angle. The postero-ventral extremity of the shell acutely angular; the ventral margin nearly straight through the greater part of its length, curving upward anteriorly to meet the hinge-line under the beak. The umbonal ridge elevated and sharply angular, slightly sigmoidal from the beak to the posterior basal angle. The postero-dorsal slope from the umbonal ridge concave, becoming more and more steep anteriorly until at or near the beak it faces dorsally, and is overhung by the umbonal ridge; the antero-ventral slope steeper than the opposite one posteriorly, but more gentle anteriorly. A shallow sinus extends from the beak obliquely across the antero-ventral slope to near the center of the basal margin. Surface marked by fine lines of growth which are most conspicuous upon the antero-ventral slope.

Remarks. The dimensions of this species as given by Winchell are somewhat greater than those recorded above, the length from the beak to the postero-ventral angle being 32 mm., and the hinge-line 20 mm. The length of the hinge-line was therefore proportionately longer than in the specimen here described. The species varies considerably in its proportions, the two specimens illustrated being representative.

MACRODON COCHLEARIS Win.

Pl. III. f. 15.

Shell subrhomboidal in outline, length, 23 mm. and height, 10 mm. Hinge-line straight, a little shorter than the total length of the shell; anterior margin meeting the hinge-line at nearly a right angle, curving regularly downward and backward into the ventral margin; ventral margin nearly straight or gently curving, except towards the extremities where it curves upward; posterior margin abruptly rounded below, truncate above, meeting the hinge-line in obtuse angle. The valves rather ventricose; beaks flattened, incurved, elevated above the hinge-line, situated at a point about one-fourth the length of the shell from the anterior extremity; the umbonal ridge rather sharply rounded near the beak, becoming more broadly rounded posteriorly, the dorsal slope from the ridge, concave. Surface marked by concentric lines of growth.

MACRODON MODESTA (Win.).

Pl. III. f. 16.

Arca modesta. Bull. U. S. G. S. No. 153: 91.

Shell small, ventricose, subovate in outline, length, 10 mm. and breadth, 5 mm. Hinge-line straight, nearly equaling the greatest length of the shell; anterior abruptly rounded; ventral margin broadly rounded; posterior margin broadly rounded from the ventral margin to the hinge-line, which it meets at an acute angle. Beak prominent, obtuse, situated near the anterior extremity of the shell, elevated above the hinge-line, but little incurved. Umbonal ridge broadly rounded, ventricose, the postero-dorsal slope concave, forming an alate expansion of the shell. Surface marked by fine, regular, sharp, concentric lines of growth.

Remarks. This shell is represented by a single specimen, the type, whose posterior portion is imperfectly preserved, this part being restored in outline in the illustration, as indicated by the direction of the lines of growth. As originally described it was referred to the genus *Arca*, but it should rather be referred, in all probability, to the genus *Macrodon*. It differs from the species of this latter genus in general, in its broadly rounded ventral margin, and its great breadth posteriorly as compared with the anterior portion of the shell. The true generic relationship of the species can of course be determined only when its hinge-structure can be known.

GRAMMYSIA PLENA Hall.

Pl. IV. f. 21.

Shell subovate or subelliptical in outline, length, 36 mm. and height, 22 mm. Hinge-line straight, more than half the length of the shell; anterior margin short, abruptly rounded below the lunule which is deep and distinct extending half way or more from the beak to the base of the shell; ventral margin regularly curved from end to end except for a slight constriction at about the anterior third; posterior margin rounded below, obliquely truncate above. Valves regularly convex in the posterior portion, becoming very gibbous in the middle and umbonal region. The beaks prominent, much elevated above the hinge-line, strongly incurved, situated near the anterior extremity; umbonal slope rounded or subangular, the postero-dorsal slope sometimes marked by a disstinct fold along the middle; a shallow sinus extends from the beak obliquely backward to the constriction in the ventral margin. Surface marked by fine concentric striae which become fasciculate posteriorly, by fine pustulose striae which can only be seen in exceptionally well preserved specimens, and by strong, subangular or rounded concentric undulations which are strongest anterior to the umbonal ridge, being replaced posteriorly by the fascicles of fine concentric striae.

Remarks. This species has often been confused with *G. hannibalensis*, but it differs from that species in its much greater gibbosity, and in its more anterior beaks. The species exhibits a good deal of variation in its proportions and general outline. In some specimens the truncation of the posterior margin is much more pronounced than in the specimen illustrated, and the ventral margin may be much more strongly curved.

GRAMMYSIA AMYGDALINUS (Win.).

Pl. IV. f. 16.

Glossites amygdalinus (in part). Bull. U. S. G. S. No. 153: 289.

Shell moderately convex, 24 mm. long and 11 mm. high. Hinge-line long, arcuate; anterior margin rather abruptly rounded; ventral margin nearly straight in the middle, gently curving upward towards each extremity; posterior margin arcuate, oblique, meeting both the cardinal margin above and the ventral margin below in rounded angles. Beak situated about one-fourth the length of the shell from the anterior extremity, elevated above the hinge-line, somewhat flattened, incurved and pointed forward. An obtusely subangular or rounded umbonal ridge extends from the beak to the postero-ventral angle. Posterior to the beak, just below the dorsal margin and parallel with it, there is a groove-like depression which gives to the cardinal margin an angular, ridge-like appearance, the upper slope of which is sharply inflected. Anterior to the beak on the dorsal margin, there is a deep lunette. Surface marked by strong concentric wrinkles which are more conspicuous towards the ventral and posterior margins. A broad, shallow, ill-defined sinus or mere flattening of the shell runs from the beak to a point in front of the middle of the ventral margin.

Remarks. Five specimens in the University of Michigan collection are attached to the card marked "Types" and bearing the label of this species. Three of these specimens are quite distinct from the other two, and are evidently members not only of a distinct species but of another genus as well. Winchell's description and the dimensions given by him, agree with one of the two specimens which are distinct from the other three, and this specimen is undoubtedly the type of the species and is here illustrated. It is apparently to be referred to the genus *Grammysia.* It resembles *G. hannibalensis* but is a smaller, longer, and more slender shell. It also differs in the same manner from *G. plena* H. with which it is associated, but the difference is even more striking. Hall * has identified a shell from the "yellow sandstone" at Burlington with this species of Winchell's, referring it to the genus *Glossites.* This shell, however, is quite distinct from Winchell's type of the species and is probably identical with the species described by him as *Edmondia elliptica* which is transferred to the genus *Glossites* in the present paper. The generic position of the three specimens associated with the type of the species is somewhat uncertain, but they certainly constitute an undescribed species which possibly should be referred to the genus *Glossites*, though they are distinct from the species identified as *G. amygdalinus* by Hall.

EDMONDIA BURLINGTONENSIS W. & W.

Pl. IV. f. 1–2.

"Shell of medium size, broadly subelliptical in outline, with regularly ventricose valves, breadth equal to three-fifths of the length. Beaks situated within the anterior third, strong, prominent and incurved. Hinge-line and basal margin gently and equally curved; anterior and posterior extremites broadly and equally rounded.

"Surface marked by numerous strong, concentric undulations, parallel to the margin of the shell. In full-grown individuals there is a shallow, undefined sulcus, commencing near the center of the shell, and reaching the border near the middle of the basal line."

Remarks. The type specimens of this species are seven in number, ranging in size from 10 mm. to 35 mm. in length. Two of the best preserved of these are here illustrated. The specimens figured by Hall were not the type specimens, and show some slight variation

* Pal. N. Y. 5^1: 501. *pl. 40. f. 13, 14.*

from the types. The specimen which he separated from *E. burlingtonensis* and described under the specific name *ellipsis* should not be so separated. *E. ellipsis* therefore becomes a synonym of *E. burlingtonensis*. Some of the variations of *E. subovata* H. from the Chemung in New York and Pennsylvania, approach very close to the Burlington species. In fact, in his earlier publications,* Hall identified this Chemung species as *E. burlingtonensis*, it being separated only in the final publication of the New York Paleontology. The Chemung species exhibits a greater variation than the Burlington species and for this reason it may perhaps be considered as distinct, but some of its variations † are certainly identical with the shell from Burlington.

EDMONDIA QUADRATA (W. & W.).

Pl. IV. f. 17.

Microdon quadratus. Bull. U. S. G. S. No. 153: 353.

Shell small, subquadrangular in general form, length 12 mm., height $9\frac{1}{2}$ mm., thickness of the two valves 7 mm., greatest convexity of the valve posterior to the beaks along the umbonal ridge. Hinge-line slightly arcuate, gradually sloping to the posterior margin; anterior and posterior margins subparallel; ventral margin greatly rounded. Beaks small, slightly incurved; umbonal ridge obscurely angular, gently arcuate. Surface marked by fine concentric lines of growth and by a few coarser concentric wrinkles.

Remarks. When this species was originally described it was referred to the genus *Cypricardella*. More recently it has been shown by Whitfield ‡ that the genus *Cypricardella* is not distinct from *Microdon* and for that reason this species has sometimes been referred to the latter genus. Upon comparison of the type specimens of the species with authentic specimens of *Microdon*, however, it is believed that it is more probably an *Edmondia* although the essential generic characters cannot be seen.

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* Prelim. Notice Lamell. 2: 90 (1870).— Pal. N. Y. 5^1. Plates and Explanations. *pl. 64. f. 19–29* (1883.)

† Compare Pal. N. Y. 5^1. *pl. 95. f. 12.*

‡ Bull. Am. Mus. Nat. Hist. 1 : 63.

EDMONDIA AEQUIMARGINALIS Win.

Pl. IV. f. 3.

Shell subcircular in outline, length, 23 mm., height, 20 mm., greatest convexity of each valve, 6 mm. Beaks central, the anterior and posterior cardinal slopes at right angles with each other. The pallial margin regularly rounded. Surface marked by rather fine concentric striae of growth with an occasional stronger furrow.

Remarks. This species was originally described as *Cardinia aequimarginalis* Win., from Marshall, Michigan. At a later date the species was identified by its author from the "yellow sandstone" at Burlington, and the species transferred to the genus *Edmondia.* The specimen here illustrated and described is the one from which the latter identification was made. It is rather an imperfect specimen which is possibly but a variation of *E. nitida.*

EDMONDIA NITIDA Win.

Pl. IV. f. 4.

"Shell small, equivalve, suborbicular, ventricose, slightly oblique, with a subcentral beak. Hinge-line slightly extended posteriorly, obtusely rounded at the extremities; anterior and posterior sides subparallel; ventral border circularly rounded, but a little produced in the line of the umbonal ridge. Beak elevated above the hinge, obtuse, slightly incurved; umbonal ridge making an angle of 68° with the hinge-line; behind this ridge the slope is abrupt to the posterior border; middle portion of the shell very slightly flattened from the beak along the region anterior to the umbonal ridge. Surface handsomely marked by rigid, regular, concentric, raised striae, with a few remote, irregularly-distributed concentric furrows. The striation is preserved in all its sharpness to the very hinge-border." Length of shell, 16 mm., height, 15 mm., convexity of each valve, 5 mm.

Remarks. This species resembles quite closely some of the illustrations of *E. obliqua* Hall * from the Chemung fauna in New York, and the two species are certainly closely allied.

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* Compare Pal. N. Y. 5[1]. *pl. 64. f. 16.*

It is also closely allied to *E. philipi* Hall, also from the Chemung.

EDMONDIA JEJUNUS (Win.).

Pl. IV. f. 5.

Sanguinolites jejunus. Bull. U. S. G. S. No. 153: 538.

"Shell of moderate size, equivalve, transverse; beaks small, barely elevated above the hinge, slightly inflected, one-third the shell-length from the anterior end; height fully half the length; hinge-line extended; dorsal slope erect, marked by an internal ridge; margin slightly inflected, if at all, though some indication exists of a very narrow escutcheon; anterior lunette equally inconspicuous; ventral margin symmetrically arcuate between the extremities, with which it connects by similar gradually increasing curvatures; posterior end truncate for a short space near the termination of the hinge-line, with which it forms an angle of about 130°; anterior end semi-elliptically rounded. Valves somewhat appressed; greatest distension one-fourth the distance from the beak to the center. Surface of cast marked by faint lines of growth. Length 21 mm., height 12 mm."

Remarks. This species was originally referred to the genus *Sanguinolites*, but its characters, so far as they are preserved, seem rather to ally it to the genus *Edmondia*. It differs from most of the species of *Edmondia*, however, in its greater proportional length. The specimen illustrated is the best preserved one of the types of the species in the University of Michigan collection, and as its dimensions correspond with those given by Winchell, it is believed to be the specimen from which he drew up his description. There are two other specimens of the same species, both of which are somewhat smaller than the one illustrated.

SPHENOTUS RIGIDUS (W. & W.).

Pl. IV. f. 9.

Shell elongate, subtriangular or elongate subpentagonal in outline; length, 25 mm., breadth, 12 mm. Hinge-line straight posteriorly, arcuate in front; anterior margin short, regularly rounded, merging into the ventral margin below; ventral margin straight, sometimes slightly emarginate a little in front of the middle; posterior margin nearly vertically truncate below, meeting the ventral margin in a rounded right angle, and obliquely truncated above, this upper portion meeting both the hinge-line above and the lower portion of the posterior margin below, in obtuse angles, giving to the posterior margin of the shell a very angular outline. Beak elevated above the hinge-line, flattened, incurved, directed forward, situated at a point about one-fifth the length of the shell from the anterior extremity. From the beak to the postero-ventral angle there is a prominent, angular umbonal ridge, with another similar but less conspicuous ridge extending from the beak to the angle in the middle of the posterior margin. An ill-defined, shallow but rather broad sinus, which is sometimes a mere flattening of the shell, extends from the beak obliquely to a point in front of the middle of the ventral margin. The greatest convexity is on the umbonal ridge at about the middle of the shell. Surface marked by rather sharp, irregular, crowded, concentric lines of growth.

Remarks. The specimens indicated as the " type," of this species in the University of Michigan collection are two in number, a larger one imperfectly preserving both valves, and a smaller, nearly perfect left valve. Hall's illustration* of the species was drawn from the larger one of these two specimens, but the figure is to a large extent restored with no indication of the restored portions. The figure here published is based upon the second of the two types above mentioned. The larger specimen is 38 mm. in length and has sharper and more irregular lines of growth.

SPHENOTUS BICARINATUS (Win.).

Pl. IV. f. 10.

Edmondia bicarinata. Bull. U. S. G. S. No. 153: 242.

Shell small, strongly convex, subelliptical in outline; length 13 mm., breadth, 6½ mm. Hinge-line straight posteriorly, bending downward in front; anterior margin short, rather sharply rounded; ventral margin slightly arcuate, subparallel with the dorsal margin; posterior margin rounded. Beaks a little elevated above the hinge-line, flattened, incurved, directed

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* Pal. N. Y. 5^1. *pl. 66. f. 14.*

forward, situated at a point about one-fifth the length of the shell from the anterior end. A prominent, subangular umbonal ridge extends from the beak to the postero-ventral margin, and midway in the dorsal slope there is another similar but less prominent ridge. The greatest convexity is near the middle of the valve, upon the umbonal ridge. Surface marked by fine, concentric lines of growth.

Remarks. This species resembles *S. rigidus* but is much smaller, is proportionately narrower posteriorly, and lacks the strongly angular posterior margin. It is possible that this species is but a small or immature form of *S. rigidus*, but the specimen illustrated seems to be an adult shell. The specimens indicated as "types" of this species in the University of Michigan collection, are four in number, the best preserved of which is here illustrated.

SPHENOTUS IOWENSIS (Win..)

Pl. IV. f. 7.

Sanguinolites iowensis. Bull. U. S. G. S. No. 153: 538.

Shell subelliptical in outline, length, 26 mm., height, 13 mm. Hinge-line arcuate, the dorsal margin sharply inflected to form a long cartilage groove; anterior margin sharply rounded above to the anterior extremity of the hinge-line under the beak, regularly rounded below; ventral margin gently curved; posterior margin short, truncate, meeting the ventral margin in a sharply rounded angle, and the dorsal margin in an obtuse angle. Beaks elevated above the hinge-line, somewhat flattened, incurved and directed forward over a deep lunette. A prominent, sharply angular or carinate, slightly sigmoid umbonal ridge extends from the beak to the postero-ventral angle, and a still sharper ridge along the dorsal margin of the shell bounding the long cartilage groove; the twisted, flattened triangular space between these two ridges is marked by three faint, depressed lines radiating from the beak. Surface marked by irregular lines of growth which are most conspicuous on the anterior portion and faintest on the postero-dorsal slope.

Remarks. The above description is based upon the specimen of the species marked "type" in the University of Michigan collection, and which also agrees with Winchell's description and dimensions. Associated with this specimen, however, and attached to the same card, are other specimens which seem to be distinct. Winchell recognized this other form and mentioned it in his description, but was not inclined to consider it as specifically distinct from the type. These two shells, however, seem to be entirely distinct, and in the material examined there are no intermediate connecting forms, so that the second form will be described here as a distinct species.

SPHENOTUS BICOSTATUS n. sp.

Pl. IV. f. 8.

Shell subelliptical in outline, strongly convex, length, 29 mm., width, 14 mm. Hinge-line arcuate; anterior margin curving abruptly inward to the anterior extremity of the hinge-line under the beak, more gently and regularly curved below; ventral margin straight or gently curved through the greater part of its length but more strongly curved upward both anteriorly and posteriorly; posterior margin sharply rounded below, obliquely truncated above. Beak elevated above the hinge-line, flattened, incurved, directed forward, situated about one-fourth the length of the shell from the anterior end. A prominent, rounded, umbonal ridge extends from the beak to the postero-ventral margin; the postero-dorsal slope is marked by two additional subangular ridges radiating from the beak, one just at the dorsal margin and another midway between the dorsal margin and the umbonal ridge. The dorsal margin is sharply inflected to form a groove for the attachment of the ligament, and the area between the dorsal marginal ridge and the median one is concave. The greatest convexity is near the middle of the valve on or just below the umbonal ridge. A shallow, ill-defined sinus extends from the beak obliquely backward to a point anterior to the middle of the ventral margin. Surface marked by fine concentric lines of growth.

Remarks. This shell was included by Winchell in his species *S. iowensis*, the specimen here illustrated being attached to the same card with the type specimen of that species.

It seems to be distinct, however, from the specimen specifically designated as the type specimen, and furthermore, seems to be the more common form of the two. It differs from *S. iowensis* in the absence of the sharply angular or carinate umbonal ridge, and also in the additional radiating ridge upon the postero-dorsal slope. The lines of growth are also less conspicuous than in *S. iowensis*.

SPATHELLA VENTRICOSA (W. & W.)

Pl. IV. f. 12.

The types of this species are two in number, the larger one being 45 mm. in length, and 20 mm. in height; the smaller one is 21 mm. long and 10 mm. high. The shell is subcylindrical, widest behind. Hinge-line straight, about two-thirds the length of the shell; anterior end short, the margin abruptly rounded; ventral margin nearly straight or slightly arcuate throughout the greater part of its length, curving upward into both extremities; posterior margin usually regularly rounded, forming a segment of a circle, sometimes more abruptly rounded. Beak anterior, not prominent, small and closely incurved. Valves very convex, gibbous in the middle; umbonal ridge broad and ill-defined, the dorsal slope much more abrupt than the ventral. Surface marked by fine concentric lines of growth, which are sometimes fasciculate in the posterior portion of the shell.

Remarks. Of the two type specimens of this species the smaller one is illustrated, the larger one being imperfect in the anterior portion. Upon the specimens illustrated by Hall, the concentric growth lines were evidently much more irregular and fasciculate than in the original types.

CARDIOPSIS MEGAMBONATA Win.

Pl. III. f. 18.

Shell subcircular in outline, strongly ventricose, oblique; length from the beak to the postero-basal margin 25 mm., height from ventral to dorsal margin, and length from anterior to posterior margins, each 20 mm., convexity of valve, 10 mm. Hinge-line short, pallial margin regularly rounded. Beak prominent, situated anteriorly, elavated above the hinge-line, incurved; umbonal region gibbous, sloping abruptly to the dorsal and anterior margins, and much more gently to the posterior and ventral margins. Surface marked by about 50 simple radiating costae which are crowded posteriorly and anteriorly, being more widely separated in the middle of the ventral margin where they are at distances of 1 mm. apart. Besides the radiating costae there are a few concentric wrinkles at irregular intervals, which are strongest posteriorly near the hinge-line.

Remarks. This species was originally described from Michigan, from specimens very much smaller than the one here illustrated. The type of the species has never been illustrated, but this specimen from Burlington was studied by Winchell and was identified by him with his Michigan shell. The generic reference is somewhat uncertain because the hinge characters are not known. In its general appearance, however, it resembles the Carboniferous shells usually referred to *Cardiopsis*.

SCHIZODUS IOWENSIS n. sp.

Pl. IV. f. 13–14.

Shell subcircular in outline, length, 11 mm. and height, 10 mm. Hinge-line short, slightly arcuate; anterior and ventral margins regularly rounded, the posterior margin convex, obliquely truncate; the posterior basal extremity angular. Beaks moderately elevated above the hinge-line, slightly incurved, situated about one-third the length of the shell from the anterior extremity, connected with the posterior basal extremity by a slightly arcuate, subangular, umbonal ridge. The posterior slope from the umbonal ridge concave; the remainder of the shell convex, the greatest convexity above the middle. Surface of the shell smooth.

Remarks. In the White collection the two specimens used as the types of this species were attached, with others, to the card labeled *Cardiomorpha trigonalis*, the specimens on the card being designated as types. Among Winchell's types of this species, however, there are evidently two distinct species represented, one species from the Chonopectus sandstone and the other from the upper yellow sandstone horizon. The latter species is represented by a single specimen which is much larger than those from the Chonopectus sandstone, with a more triangular form and with a much more angular umbonal ridge. Judging from his description and the measurements given, Winchell considered this larger specimen as the principal type of his species, and it is therefore retained as the type of *Cardiomorpha* or rather *Schizodus trigonalis*. The smaller species from the Chonopectus sandstone requires a new name, *S. iowensis* being here proposed. This species may be compared with *S. gregarius* Hall, from the New York Chemung fauna, but it is shorter than that species. It also resembles *S. cuneus* Hall, from the Waverly series in Ohio.

SCHIZODUS BURLINGTONENSIS n. sp.

Pl. IV. f. 15.

Shell subovate in outline, depressed convex, length, 18 mm. and breadth, 11 mm. Hinge-line short; anterior margin regularly rounded; ventral margin nearly straight posteriorly, but curving upward in the anterior half; posterior margin sharply rounded below, obliquely truncated above. Beak small, but little elevated above the hinge-line; umbonal ridge arcuate, extending from the beak to the postero-ventral margin. Surface marked by inconspicuous concentric lines of growth.

Remarks. This species differs from *S. iowensis* in its much greater length. It resembles *S. gregarius* H., from the Chemung group in New York, but is a longer shell. In fact *S. gregarius* is somewhat intermediate in its characters between this species and *S. iowensis*. The specimen illustrated was attached to the same card in the University of Michigan collection, with the types of *Edmondia jejunus*, but it is entirely different from that species, not even being generically allied to it.

CYPRICARDINIA SULCIFERA (Win.).

Pl. III. f. 17.

Shell small, subovate in outline, very oblique; length, 7 mm., breadth, 4 mm. Hinge-line straight, shorter than the total length of the shell; anterior margin abruptly rounded; ventral margin nearly straight or sinuate in the middle; posterior margin abruptly rounded below, truncated above, meeting the hinge-line at an obtuse angle. Beaks nearly terminal, prominent, flattened, slightly incurved; umbonal ridge slightly arcuate, the dorsal slope concave, the ventral slope moderately convex. Greatest convexity of each valve on the umbonal ridge a little back of the beak. Surface marked by six to eight strong imbricating concentric ridges.

GLOSSITES ELLIPTICA (Win.).

Pl. IV. f. 6.

Edmondia elliptica. Bull. U. S. G. S. No. 153: 242.

"Shell rather large, appressed, transverse, with an elongate-elliptical outline. Beaks flat, inconspicuous, situated one-fifth the shell-length from the anterior end. Hinge margin elongate, slightly curved, abruptly elevated; a flattened area extending from the beaks backward to the posterior hinge angle. Extremities neatly rounded. Surface marked by numerous distinct unequal lines running parallel with the pallial margin. Length, 34 mm., height, 16 mm."

Remarks. This species is represented by a single specimen, the type, which is only an imperfect impression in the sandstone. The figure is drawn from a wax impression taken from this specimen, the probable outline of the shell being indicated. It was originally described as *Edmondia*, but in all the characters preserved it more closely resembles the illustrations of *Glossites* and is therefore transferred to that genus. It is perhaps more closely allied to *G. depressus* Hall * from the Chemung in New York, than to any other species of the genus.

GLOSSITES? BURLINGTONENSIS n. sp.

Pl. IV. f. 11.

Shell subelliptical in outline, moderately convex, compressed toward the posterior extremity; length, 28 mm., height, 13 mm. Hinge-line nearly as long as the shell; anterior margin abruptly rounding into the hinge-line above, regularly curving below into the ventral margin; ventral

* Compare Pal. N. Y. 5^1. *pl. 40. f. 17.*

margin regularly curved throughout its entire length; posterior extremity situated well towards the dorsal margin, its margin rather abruptly rounded. Beak prominent, incurved, elevated above the hinge-line, situated about two-sevenths of the length of the shell from the anterior extremity. Surface marked by concentric wrinkles which are most conspicuous anteriorly.

Remarks. The specimen selected as the type of this species was included among the "types" of *Grammysia amygdalinus* (Win.), in the University of Michigan collection. This specimen, however, along with two others associated with it, is entirely different from the real type of the above mentioned species, as determined from Winchell's original description and the dimensions given by him. These specimens, therefore, have to be considered as representatives of an undescribed species. The genus to which these specimens should be referred is uncertain since the characters of the hinge cannot be seen. The species is provisionally referred to the genus *Glossites*, for the want of any better place for it, though with the feeling that when the hinge-characters are known, it will have to be removed. It differs from *Grammysia amygdalinus* in its larger size, in its less convexity, in the absence of any well-defined umbonal ridge, and in the more dorsal position of the posterior extremity of the shell.

PROMACRUS CUNEATUS Hall.

Pl. IV. f. 20.

This species has not been observed but it was described from the "yellow sandstone" at Burlington * and possibly belongs in the Chonopectus sandstone fauna. The illustration is a copy from the original one published by Hall. A nearly complete specimen from the Vermicular sandstone at Northview, Missouri, has been identified † with this species, but the Burlington shell is much more slender anteriorly than the Northview specimens.

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* See Pal. N. Y. **5**[1] **:** 510. *pl. 78. f. 28.*

† Trans. St. Louis Acad. Sci. **9 :** 36. *pl. 3. f. 2.*

POSIDONOMYA? AMBIGUA Win.

Pl. IV. f. 18–19.

"Shell of medium size, rather ventricose, somewhat oblique. Hinge-line short, straight, not surpassed by the inconspicuous beak, abruptly rounded at the extremities; sides of shell subparallel, somewhat straight; ventral margin circularly curved, gaping at the antero-ventral angle. Cast nearly smooth, but bearing the impression of a few small, irregular wrinkles around the margin. Greatest dimension (from beak to ventral margin), 16 mm.; anterior-posterior dimension, 14 mm.

"Three left valves and one right, of an anomalous fossil are here referred with great uncertainty. One of the specimens is larger and relatively longer from beak to venter than the one described, and seems to have been everted around nearly the entire pallial border, producing an extensively gaping shell. * * * The three valves could scarcely belong to the same species of any genus, but it would be folly to attempt a further discrimination at present."

Remarks. The above is copied from Winchell's original description of this species. The smaller one of the specimens illustrated is the type of the species, judging from the description and the dimensions given. The larger illustration is of the larger specimen mentioned in the description. The proper disposition of these shells is about as uncertain now as when Winchell wrote his description. The smaller specimen closely resembles the illustration of *Paracyclas erecta* H.,* from the Chemung group at Warren, Penn., and it may be identical with it. The larger specimen may also be referable to the genus *Paracyclas*, though it is quite different from any of the recognized species of that genus. A few specimens of a small, nearly flat, smooth, oval shell, having much the form of a *Pernopecten* (see p. 85, *pl. III., f. 5*) with the ears removed should possibly be associated with the shells here described.

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* Pal. N. Y. 5^1. *pl. 95. f. 22.*

GASTEROPODA.

LOXONEMA SHUMARDANA (Win.).

Pl. VII. f. 5.

Murchisonia shumardana. Bull. U. S. G. S. No. 153: 359.

"Shell small, conical, consisting of six or seven gradually enlarging whorls, somewhat flattened on the base and outer surface, so as to leave but a shallow suture; body whorl obtusely angulated at the junction of the basal and lateral surfaces; aperture broadly cuneate-ovate, angulated behind, scarcely effuse in front; plane of aperture parallel with vertical axis of shell, surface of cast quite smooth. Height of shell, 14 mm.; height of last whorl, 6 mm.; diameter of base of shell, 7 mm.; length of aperture, 5½ mm.; greatest width, 4 mm.; apical angle, 34°."

Remarks. The specimen here illustrated is the type of this species, and is the only specimen which has been observed. The generic characters of the shell are uncertain, but it certainly is not *Murchisonia*, the genus to which it was originally referred. It is here placed in the genus *Loxonema* but not without some doubt. It resembles some of the species referred by DeKoninck to the genus *Flemingia*,* and it is possibly a member of that genus.

LOXONEMA OLIGOSPIRA Win.

Pl. VII. f. 4.

"Shell small; whorls about six, rather rapidly enlarging, convex exteriorly, with traces (on the cast) of vertical ridges, which become more observable in the vicinity of the aperture; suture deep; body whorl three-fifths the length of the shell, more rapidly enlarging than the spire, gently convex on the outer side, more rapidly curved toward the base — which is somewhat umbilicately indented — rapidly increasing in diameter toward the aperture, which is thus rendered somewhat effuse in front. Height of shell, 10 mm.; height of body whorl, 5½ mm.; diameter of body whorl, 7 mm."

Remarks. This species was founded upon a single speci-

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* See *F. Munsteri* DeK., Faun. du Calc. Carb. de la Belg. 3. *pl. 7. f. 21–22.*

men which is here illustrated for the first time. Its generic position is by no means certain, so it is retained in the genus *Loxonema* where it was originally placed. The shell probably posesses no umbilicus as is indicated by the original description quoted above, though this cannot be determined with entire satisfaction from the type specimen. The description of the surface markings is also somewhat misleading as the specimen is almost absolutely smooth with the exception of a few faint lines of growth near the aperture. There are not six volutions preserved in the type specimen, though there may have been that number in the perfect shell.

LOXONEMA sp.

Pl. VII. f. 2.

Among the specimens labeled *Murchisonia quadricincta* in the University of Michigan collection, there are several individuals which have a more elevated spire than the type of that species, with smooth, rounded volutions which are but barely in contact, the lower volutions not overlapping the upper. These shells evidently belong to the smooth shelled division of the genus *Loxonema*, though they are not sufficiently well preserved to determine their essential characters.

MURCHISONIA QUADRICINCTA Win.

Pl. VII. f. 3.

"Shell of medium size, turrited; whorls convex, regularly enlarging to the last, with an obsoletely bicarinate band running along the middle, below which are four small, rigid, thread-like approximated carinae, leaving the base of the body whorl smooth or faintly lined, and regularly curved into the umbilical cavity; the surface above the band marked only by very delicate lines of growth, which arch backwards to the peripheral band, below which they arch far forwards, entering the umbilical cavity half their length in advance of their place of origin at the suture. Suture deeply impressed. The only specimen showing the external markings has a defective spire, but could not be completed with less than 8 or 9 whorls, giving a length of 27 mm.; an apical angle of 19°, a sutural angle of 66°, while the body whorl is 6 mm. high."

STROPHOSTYLUS BIVOLVE (W. & W.).

Pl. V. f. 4–5.

Shell of medium size, composed of about two closely coiled volutions, with the spire scarcely elevated above the outer one. The inner volution small, the outer one more rapidly expanding, becoming ventricose. Cross section of the outer volution ovate, narrowest at the inner margin. Surface marked by fine transverse lines of growth, parallel to the margin of the aperture. Greatest diameter of the shell 19 mm., height of aperture, 11 m., width of aperture, 11 mm.

Remarks. This specimen is included among the types of *S. bivolve* in the University of Michigan collection, the three other specimens being from a higher horizon. The specimen believed to be the actual type from which original description was made, and which has been illustrated by Keyes,* is one of the other specimens. This single specimen observed from the Chonopectus sandstone, differs from all the others in the much greater size of the inner volution of the shell, and consequently in the less rapid expansion of the outer volution. It is possible that it should be considered as a distinct species, but it is desirable that additional specimens should first be examined in order to determine the constancy of its characters.

SPHAERODOMA PINGUIS (Win.).

Pl. VI. f. 1–2.

Shell subglobular, spire short and tapering rapidly, three greatly overlapping volutions recognizable in the type specimen, suture moderately impressed. The body volution ventricose, broadest in the middle; the aperture ovate, its longer axis forming an angle of 27° with the axis of the shell, acute posteriorly, rounded anteriorly; inner lip flattened. Surface marked by faint, transverse striae of growth. Height of the shell, 47 mm., length of aperture, 37 mm., width of aperture, 25 mm., spiral angle, 85°.

NATICOPSIS DEPRESSA Win.

Pl. VI. f. 3–4.

Shell small, narrowly umbilicate, the type specimen with

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* Mo. Geol. Surv. **5.** *pl. 53, f. 4.*

three volutions; the spire scarcely elevated above the body volution, the suture very shallow, giving the upper side of the shell a regular, gentle convexity. The last volution rapidly expanding, the aperture oblique, oval, rounded posteriorly and anteriorly, somewhat contracted on the inner side by the rather broad inner lip. Height of shell, 11 mm., greatest diameter, 16 mm., length of aperture, 11 mm., width of aperture 9 mm.

Remarks. The fine, regular, elongate nodes mentioned by Winchell as marking the upper ends of the striae of growth on the outer volution, have not been observed upon either of the two type specimens of the species in the University of Michigan collection.

STRAPAROLLUS MACROMPHALUS Win.

Pl. VI. f. 17–18.

Shell of medium size, depressed, with a slighty elevated spire and a broad umbilicus open to the apex of the spire; volutions gradually enlarging, barely in contact, with a nearly circular cross-section. Surface marked by regular lines of growth. Diameter of shell, 21 mm., height, 9 mm.

Remarks. In the type specimen of this species here illustrated, the spire is imperfectly preserved so that the number of volutions cannot be accurately determined, but there are probably not less than four and perhaps five volutions altogether.

STRAPAROLLUS AMMON (W. & W.).

Pl. VI. f. 22.

Shell small, discoid, the spire not elevated above the plane of the outer volution. Volutions three or four, closely coiled, gradually enlarging from the apex, slightly angular on the upper side, rounded below, and on the back. Umbilicus very broad, exposing nearly the whole of the inner volutions. Surface of the shell marked by fine, closely arranged transverse striae of growth, which have a gentle backward curvature from the suture line to the under side of the volution.

Remarks. The actual type specimen of this species was not found in the University of Michigan collection, but another authentic specimen is there preserved and here illustrated. In their description the authors of the species give the diameter of the largest specimen as $15\frac{1}{2}$ mm., but the specimen here illustrated is somewhat smaller, being but 11 mm. in maximum diameter. The species may be easily distinguished from its associates by its perfectly flat or even slightly depressed spire.

STRAPAROLLUS ANGULARIS n. sp.

Pl. VI. f. 13–14.

Shell of medium size with four volutions; spire not greatly elevated above the outer volution, the suture located in an angular groove. The top of each volution flat or sloping inward, the outer side rounded, meeting the flattened upper side in an obtuse angle so that the shell is marked with a conspicuous, angular, revolving ridge, and the successive volutions form a series of steps from the outer one to the summit of the spire. The surface of the shell marked by somewhat irregular lines of growth which curve gently forward on the outer side of the last volution. Greatest diameter of the shell, 21 mm.

Remarks. The specimen here illustrated is a plaster cast taken from a natural mould in the sandstone. The under side of the shell is not known but it is probably umbilicate. The specimen bears the name *S. obtusus* in the University of Michigan collection, but it is certainly distinct from that species which has a discoid shell with little or no elevation of the spire above the outer volution. The species is quite distinct from any of its associates and seems to be as yet undescribed. It most closely resembles *S. luxus* White, described from near the base of the Carboniferous strata in Utah, but it differs from that species in having a somewhat higher spire. It also resembles *S. planodorsatus* M. and W., from the Kaskaskia beds in Southern Illinois and Missouri.

PLATYSCHISMA BARRISI (Win.).

Pl. VI. f. 15–16.

Straparollus barrisi. Bull. U. S. G. S. No. 153: 604.

Shell of medium size, depressed conical in form, with a medium sized, rather deep umbilicus; volutions four or five in number, gradually expanding, the suture rather strongly impressed; cross section of each volution subcircular in outline. The outer volution with a barely perceptible, depressed, rounded, revolving ridge a short distance below the suture, marking the position of a moderately deep rounded notch in the peristome. Greatest diameter, 25 mm., height of shell, 18 mm., approximate diameter of umbilicus, 7 mm.

Remarks. The genus *Platyschisma* is distinguished from *Straparollus*, where this species has always been placed, by the presence of a notch of greater or less depth in the peristome in its outer posterior half. This notch resembles that in the peristome of the *Pleurotomaridae*, but it does not result in forming a conspicuous revolving band, so that unless the actual margin of the aperture is preserved it is impossible to separate the species from *Straparollus*. The genus *Platyschisma* is represented by several species in the Carboniferous faunas of Europe, but it has heretofore been definitely recognized in America only in the Vermicular sandstone fauna at Northview, Missouri.* In the type specimen of *P. barrisi* here illustrated, the peristome is perfectly preserved through a greater part of its length, and the notch is well shown. The summit of the spire is imperfect in the type specimen so that the actual number of volutions in the shell cannot be determined, but another specimen preserves at least four volutions.

PLATYSCHISMA DEPRESSA n. sp.

Pl. VI. f. 19–21.

Associated with *P. barrisi* and attached to the same card marked "types" in the University of Michigan collection, there is a specimen which differs from it in being a much more depressed shell with a much deeper notch in the peristome, and in having the notch at the middle of the outer side of the whorl instead of in the dorsal part of the outer

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* Trans. Acad. Sci. St. Louis. **9**: 42. *pl. 5. f. 1–4.* — In this place the author is made to state, by the omission of the word *definitely*, that the genus has never before been recognized in America. Two species have in fact been referred by their authors to the genus,— *P. dubium* Dawson, and *P. helicoides* M. & W., — but neither of them is certainly or even probably a member of the genus.

side near the suture. It is believed that this specimen represents a distinct species and the name *P. depressa* is proposed for it. The type specimen has a diameter of 16 mm. and a height of 9 mm., with an umbilicus whose approximate width is 4 mm.

PHANEROTINUS PARADOXUS Win.

Pl. VII. f. 1.

Shell discoid, with three gradually and regularly expanding volutions disjoined throughout their entire extent, the inner ones depressed below the plane of the outer. Cross-section of the volutions subcircular. Surface marked by faint, transverse lines of growth. Diameter of shell, 25 mm., width of the outer volution at the aperture, 8 mm.

Remarks. The illustration of this specimen published by Hall * is in error in showing the inner volutions in contact, and also in making the transverse lines of growth too strong. It is possible that this shell should be considered as sinstral rather than dextral. If it is a dextral shell, then the depression of the inner volutions is so great that the under side is more nearly in a plane than the upper, while if it be a sinstral shell the inner volutions are but slightly depressed below the plane of the outer one, and the under side is broadly umbilicate.

The types of this species are wax casts from a natural mould which has not been seen and which is probably lost, and it is not certain that the species is a member of the Chonopectus fauna, as it may belong in the upper "yellow sandstone."

BELLEROPHON BILABIATUS W. & W.

Pl. VI. f. 9–10.

Shell of medium size, subglobose, narrowly umbilicate; the inner volutions expanding somewhat gradually, the outer volution rather broadly expanded at the aperture. The outer volution with a narrow subangular dorsal band, becoming more prominent and carinate towards the aperture. The outer lip deeply notched, giving the aperture a strongly

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* Pal. N. Y. 5[1]. *pl. 16. f. 16.*

bilobed outline. Surface nearly smooth, but with a few faint undulations parallel with the margin of the aperture, and sometimes with very fine, faint lines of growth.

Remarks. The specimen here illustrated is the most perfect one of the three types in the University of Michigan collection. The specimen referred to this species and illustrated by Keyes * is very different from the types, and should possibly be referred to *B. panneus* although it is a much more perfect specimen than the types of that species.

BELLEROPHON VINCULATUS W. & W.

Pl. VI. f. 11–12.

Shell of medium size, subglobose, not umbilicate. Volutions expanding somewhat gradually to the aperture. Outer lip deeply notched. Dorsal band rather broad, bounded on either side by a narrow raised rib. The sides of the shell marked by transverse striae which originate at the margins of the dorsal band and pass with a gentle forward curve toward the axis of the shell; these striae most conspicuous near the aperture, becoming obsolete on the upper part of the shell.

Remarks. No specimen marked as the type of this species was found in the University of Michigan collection, although it should be preserved in that place. The somewhat distorted specimen here illustrated, however, is present in that collection and may be the type although not so labeled. In size this species corresponds with *B. bilabiatus*, but it may be easily distinguished from that species because of the absence of the expanded aperture and the presence of the conspicuous transverse striae.

BELLEROPHON PANNEUS White. ?

Pl. VI. f. 7–8.

Shell of rather more than medium size, rather broadly umbilicate, gradually expanded to the aperture, transverse section of the volutions subelliptical in outline. Outer lip broadly notched; dorsal band narrow, subcarinate towards the aperture. The lateral surfaces of the shell marked by transverse

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* Mo. Geol. Surv. **5.** *pl. 50. f. 3.*

lines of growth which become stronger towards the margin of the aperture. Width of the outer volution at the aperture, 25 mm., distance from the outer lip to the opposite side of the volution, 22 mm., height of the shell above the plane of the aperture, 13 mm.

Remarks. This specimen is identified doubtfully with *B. panneus.* The types of the species are two imperfect and distorted specimens from a horizon somewhat higher than the Chonopectus sandstone. The better preserved of the two is several times larger than the specimen here illustrated, but their general form and proportions are about the same. In the typical *B. panneus* there are three or four stronger lines of growth near the aperture, but this is not believed to be a very essential difference. The species may be easily distinguished from *B. bilabiatus* by its larger size, its larger umbilicus and the absence of the expansion of the outer volution at the aperture.

The specimen illustrated by Keyes* as *B. panneus* has no resemblance whatever with the type of the species, and is probably an undescribed form. The specimen illustrated by the same author† as *B. bilabiatus*, however seems to be a good example of *B. panneus.*

BUCANOPSIS DEFLECTUS n. sp.

Pl. VI. f. 5.

Shell small, subglobose, umbilicate, the volutions gradually expanding to within one or two mm. from the aperture, where the margin of the shell is abruptly deflected. Cross-section of the volutions subelliptical; aperture subelliptical, the outer lip with a moderately shallow notch. The revolving dorsal band narrow, flat on top, becoming obsolete a short distance from the aperture. The surface of the shell marked by very fine revolving striae which become almost obsolete a short distance from the aperture, and by even more faint lines of growth. In the type specimen, at a short distance from the aperture where the dorsal band and the revolving striae become obsolete, there is a strong, transverse rounded groove

* Mo. Geol. Surv. 5. *pl. 50. f. 6.*

† Loc. cit. *pl. 50. f. 3.*

which traverses the whole outer side of the shell. Width of the aperture, 9 mm., length, 7 mm., height of shell above the plane of the aperture, 5 mm.

Remarks. Waagen * referred all the *Bellerophon*-like shells with spiral sculpture to the genus *Bucania*, and he was followed by DeKoninck † in his work on the Carboniferous fossils of Belgium. It has been shown by Ulrich ‡ however, that a part of these shells in which the revolving striae are parallel with the dorsal band instead of oblique to it, should be separated from *Bucania*, and he has proposed the generic name *Bucanopsis* for these species. The species here described differs from the usual form of the members of this genus, in the less rapid enlargement of the volutions and also in the abrupt deflection of the margin of the shell as it approaches the aperture.

Upon the card in the University of Michigan collection marked "Types" and labeled as *Bellerophon perelegans*, there are no less than three distinct species from two distinct horizons. Two of the specimens, from a horizon higher than the Chonopectus sandstone, are apparently the actual types of *B. perelegans*, but the species should rather be referred to the genus *Bucanopsis.* The seven other specimens are from the Chonopectus sandstone, six of them being good typical specimens of *Bellerophon bilabiatus*, the seventh being the specimen here described. It differs markedly from *B. perelegans* in the more gradual enlargement of the volutions and in the deflected margin. The revolving striae are also somewhat coarser near the aperture, and as it can be identified with no described species it is here described as new.

PATELLOSTIUM SCRIPTIFERUS (White).

Pl. VI. f. 6.

Bellerophon scriptiferus. Bull. U. S. G. S. 153: 144.

Shell ventricose, closely coiled, the umbilicus small; inner volutions subglobose, subelliptical in cross section, the last half of the outer volution abruptly expanding towards the aper-

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* Pal. Ind. XIII. 1: 130.

† Faun. du Calc. Carb de la Belg. Pt. 4.

‡ Pal. Minn. 2: 853.

ture into a broad, subcordate disk. The outer lip of the peritome with a small, shallow dorsal notch, the inner lip spreading over the preceding volution. The dorsum marked by a narrow ridge or carina in the outer half of the last volution, but beyond this the dorsum is flattened. The expanded portion of the outer volution is marked by a few, shallow, inconspicuous wrinkles parallel with the margin; the smaller part of the shell marked by three or four faint revolving ribs on each side, which are entirely obsolete in some specimens. Transverse diameter of the aperture, 42 mm., the longitudinal diameter, 33 mm., the height of the shell above the aperture, 12 mm.

Remarks. In general form this species resembles *P. patulus* from the Hamilton group of New York, but the aperture is more transverse, and the concentric wrinkles are not nearly so strong.

PORCELLIA CRASSINODA W. & W.

Pl. V. f. 1–2.

Shell large, discoid, broadly umbilicate, consisting of three or four contiguous or slightly embracing whorls, which rapidly increase in size towards the aperture; the greatest diameter, 83 mm. Volutions subtriangular in transverse section, rapidly increasing in diameter from the ventral to the dorsal side; at the aperture the ventral diameter is 11 mm., and the dorsal, 43 mm., to the tips of the nodes. Lateral surfaces slightly convex; the dorsum gently rounded, marked along the middle by a shallow double groove indicating the position of the slit in the aperture. The dorso-lateral angles ornamented by a single row of distant, strong, obtusely pointed nodes; in the type specimen the nodes on one side are a little in advance of those on the other. Surface marked by fine, revolving and transverse striae which are strongest on the dorsum. On the dorsum the transverse striae slope backward from each side to the central groove where they meet at an angle of about 120°.

PORCELLIA OBLIQUINODA White.

Pl. V. f. 3.

Shell of medium size, discoid, broadly umbilicate, consisting of four or perhaps more slightly embracing volutions which increase in size somewhat rapidly towards the aperture; the greatest diameter of the type specimen, which is incomplete, 30 mm. The inner volutions subcircular in transverse section, the outer one becoming remotely subtriangular, the diameter of the whorl at the largest part of the shell, 18 or 20 mm. The lateral surfaces convex; the dorsum rounded, marked along the middle by a shallow groove. The dorsolateral angles ornamented by a single row of rather small, moderately elevated, oblique nodes, whose outer ends are directed backward; the nodes increase in size with the growth of the shell, they being nearly obsolete upon the inner whorls. The surface of the type specimen is smooth.

Remarks. In its smooth surface this species is unlike most of the species of the genus, but the type specimen is a cast, and it is possible that the external surface of the shell was marked by the usual revolving and transverse striae.

PORCELLIA RECTINODA Win.

This species was described by Winchell from the "yellow sandstone" at Burlington, and although it has not been observed, it is possibly a member of the Chonopectus sandstone fauna. Judging from the description it resembles *P. obliquinoda* but is much smaller, the type specimen having a maximum diameter of 15 mm. with the diameter of the outer whorl at the aperture scarcely 5 mm.; it also differs from *P. obliquinoda* in the more nearly circular section of the whorls and by the transverse, rather than the oblique, direction of the nodes. Specimens from the Vermicular sandstone at Northview, Missouri, have been compared* with this species, though they are considerably larger.

SCAPHOPODA.

DENTALIUM GRANDAEVUM Win.

Pl. VII. f. 6.

"Shell rather large, perfectly straight and terete, or a little compressed, tapering 1 mm. in 12 mm. near the larger

* Trans. St. Louis Acad. Sci. 9: 43. *pl. 5. f. 7.*

end, less rapidly near the small end; surface marked by faint, irregular lines of growth which run obliquely around the shell, and in flattened specimens are more advanced along one edge. Length of largest specimen, 56 mm.; diameter at larger end 5 mm.; at smaller end about 1 mm."

PTEROPODA.

CONULARIA BYBLIS White.

Pl. VII. f. 7.

Shell large, elongate pyramidal; the lateral surfaces nearly flat, their margins diverging at an angle of about 15°, marked along the mesial line by a slight depression; transverse costae somewhat variable in their distances apart, there being from 12 to 18 in a distance of 10 mm., each costa forming at the median line of the lateral surface a rounded, obtuse angle of about 120°; the spaces between the costae crenulate. The angles of the shell at the lines of junction between adjacent lateral surfaces are marked by narrow grooves formed by the incurved margins of the sides. The dimensions of the type specimen cannot be accurately determined because of its crushed and distorted condition, its maximum length as preserved is 76 mm., and its greatest width 54 mm.; if the sides of the shell be projected to a point its length is nearly twice the present length of the specimen.

Remarks. The specimen here illustrated is the type. In the figure the transverse costae are made to form too abrupt an angle as they cross the median line of each lateral surface, this angle should be more rounded. One specimen referred to as a variety of this species in the University of Michigan collection, is somewhat larger than the one illustrated although it is much more crushed and distorted. It differs from the type in having the transverse costae somewhat closer together and in having them conspicuously crenulate. There are still other more fragmentary specimens which show various degrees of crenulation of the costae, and also a considerable variation in the distances separating the costae. It therefore seems, either that this species is a very variable one, or that two or more distinct species of *Conularia* are present in the fauna, although not sufficiently well preserved specimens have yet been found to admit of determining their distinguishing characters.

CEPHALOPODA.

Orthoceras whitei Win.

Pl. IX. f. 4–5.

Shell annulated, gradually tapering at an angle of about 5°; subelliptical in cross-section; septa deeply concave, situated at distances of about 4–5 mm. At the largest end of the largest type specimen, the longer diameter of the cross-section is 32 mm., and the shorter 25 mm. The annulations are sharply angular or rounded, separated by regularly concave furrows; ten of them occupy a space of 63 mm. In the smaller specimens referred to this species, the annulations and septa are much closer together, and sometimes the annulations have a broad, shallow, retral sinuosity. Siphuncle rather large, situated excentrically along the longer diameter. Surface of the casts marked by fine encircling striae which are parallel with the annulations, in some specimens being obsolete.

Remarks. This species is not uncommon in the Chonopectus fauna, though it exhibits a considerable range of variation in size. The two specimens illustrated are both included among those labeled as type specimens in the University of Michigan collection. The larger one probably represents about the maximum size of the species. The species belongs to the annulate division of the genus which is represented by several species in the Devonian faunas in America, but which is uncommon in the Carboniferous.

Orthoceras heterocinctum Win.

Pl. IX. f. 6.

This is an annulated species closely allied to *O. whitei*, and is possibly no more than a variety of that species. None of the type specimens are as large as the largest *O. whitei*, and the annulations are much more unequal, in some specimens being nearly obsolete and in others being nearly obsolete in parts of the shell. The cross-section of this species is circular rather than elliptical as in *O. whitei*, although the elliptical cross-section of the latter species may be due to a slight compression of originally cylindrical shells. It is said by Winchell that this species tapers more rapidly than *O. whitei*. This may be true in general, but the two species overlap in this characteristic, the type specimens of *O. whitei* varying from 5° to 8° and *O. heterocinctus* from 6° to 10°. The material representing both these species, leaves much to be desired, it being for the most part fragmentary, and the species can be properly defined only when more perfect specimens are procured.

ORTHOCERAS INDIANENSE Hall.

Pl. IX. f. 3.

Several specimens of a small, smooth species of *Orthoceras* with the sides tapering at an angle of about 8° with a circular or slightly elliptical cross-section, and with a central or slightly excentric siphuncle, have been observed in the Chonopectus fauna. These were referred to the species *O. indianense* by Winchell, and they seem to present no characters upon which they can be separated from that species. The specimens are all mere fragments, and more perfect material is needed to certainly determine their essential characters.

PHRAGMOCERAS EXPANSUM Win.

Pl. IX. f. 2.

Shell straight, rapidly expanding at an angle of about 70°, very slightly constricted near the aperture. Transverse section of the shell broadly elliptical, approaching circular. Septa at distances of about 6 mm. Surface smooth in the cast. The type specimen has a total length preserved of about 35 mm., 21 mm. of which is included in the living chamber; the longer diameter of the aperture is 52 mm. and the shorter 45 mm., at the first septum the longer diameter is 33 mm. and the shorter 27 mm.

Remarks. The characters of this species are not very definitely preserved. The specimen illustrated is the type, and is the only one which approaches perfection, even remotely. Several other fragments are preserved in the University of Michigan collection and labeled as this species, but it is by no means certain that they are all the same.

CYRTOCERAS UNICORNE Win.

Pl. VII. f. 9.

Shell arcuate, angle of divergence rapidly increasing with the growth of the shell; transverse section laterally compressed, oval in outline, narrowest along the side of least curvature. Living chamber large, expanding towards the margin; septa at distances of about $3\frac{1}{2}$ mm., regularly concave. Siphuncle apparently marginal along the side of least curvature. Surface smooth except for some irregular lines of growth near the aperture. In the type specimen the septate portion is 29 mm. in length and the living chamber 22 mm.; the greatest diameter of the aperture is 40 mm. and the shorter diameter 34 mm.; at the first septum the longest diameter, 24 mm., and at the seventh septum, the last one perfectly preserved, the longest diameter is 16 mm.

Remarks. There are several fragmentary specimens of curved cephalopods in the University of Michigan collection, all of which bear the label *C. unicorne*. The type specimen here illustrated, however, is the only one sufficiently well preserved to exhibit any of its essential characters.

AGONIATITES OPIMUS (W. & W.).

Pl. VII. f. 8. Pl. VIII. f. 1. Pl. IX. f. 1.

Goniatites opimus. Bull. U. S. G. S. No. 153: 295.

Shell large, discoid, gently convex on the sides, rather sharply rounded upon the periphery. Number of volutions not known, the inner ones embraced by the next outer ones to a depth of one-half the diameter of the latter; the umbilicus rather small, but somewhat variable in size, being relatively larger in the larger individuals, its sides rounded. Aperture compressed crescentic in outline, the proportion of height to width about as 7 to 5, the ventral margin sinuate as indicated by the lines of growth. The size of the living chamber not known. Septa deeply concave, rather distant; being about 20 mm. apart in the outer volution of a large individual; the sutures forming a low saddle upon the umbilical angle, then gently curving backward and forming on each lateral face a single broad lobe which occupies the entire width of the volution; the direction of the suture upon the periphery cannot be certainly determined, but there seems to be a low saddle on either side, with a shallow ventral lobe between. Position of the siphuncle unknown. Surface marked by very faint lines of growth which are sinuate on the periphery of the shell.

Remarks. In the original description of *Goniatites opimus*, specimens of two entirely different species were apparently used, the general form of the shell being described from one specimen, and the suture from another. The specimen here illustrated on plate VII, figure 8, is the type of the species in the University of Michigan collection, and corresponds with original description of the general form and proportions of the shell. This specimen, however, does not preserve the suture, and the original specimen from which the suture was described has not been seen. This latter specimen was probably a fragmentary one not preserving the form of the shell, which was believed to belong to the same species as the type which has been preserved. In the collection received from Prof. Calvin there is a goniatite much larger than the type of *G. opimus* but agreeing closely with it in its general form and proportions in all respects save in its relatively larger umbilicus. This specimen is illustrated on plates VIII and IX, and it is believed to be an individual of the same species as the type of *G. opimus;* but unlike the type specimen several of the sutures are fairly well preserved, and are entirely different from the sutures of *G. opimus* as indicated in the original description. It is therefore probable that the suture originally described as that of *G. opimus* is really the suture of some shell which is not only specifically, but generically, distinct from *G. opimus*. The true suture of the species is in all respects that of the genus *Agoniatites*, and therefore the species is placed in that genus. Heretofore this genus has been recognized only in the Devonian, and in America, at least, at no higher horizon than the Middle Devonian.

Correlation.

Attention should again be called, at this point, to the diverse and local character of the lithologic formations and of the faunas of the Kinderhook epoch. It is not possible, as has been the usual custom, to recognize three constant divisions of the Kinderhook, either lithologic or faunal, well defined throughout the whole area in Iowa, Missouri, and Illinois, occupied by the rocks of this age. The names Louisiana limestone, Hannibal shale, and Chouteau limestone, cannot be applied to all the Kinderhook formations throughout the area, and as investigations are prosecuted in various localities, other local formation names will have to be introduced.

No satisfactory correlation of the Kinderhook beds at Burlington with those of Illinois and Missouri, has yet been made. Keyes* has referred nearly the whole of the section at Burlington to the Hannibal shales of Northwestern Missouri, but his basis for this correlation seems to have been chiefly the lithologic similarity. It is far more probable that the section at Burlington is equivalent, or more than equivalent, to the whole of the section as known in Missouri. On lithologic grounds alone, bed No. 4 (Weller) at Burlington, might well be considered as a northern extension of the typical Louisiana limestone of Missouri, reduced in thickness. In both localities the rock is a fine-grained, compact, fragmentary limestone, though at Burlington its fragmental character is more pronounced and more irregular than at Louisiana. Fossils are not abundant in this bed at Burlington, so that an entirely satisfactory comparison of the faunas cannot be made. However, the species of *Syringothyris* which occur at the two localities, seem to be identical, although the Burlington

* Geol. Surv. Iowa. 1 : 55. (1893.)

specimens described by Winchell as *S. Halli* are smaller than the Louisiana examples.

If it be true that bed No. 4 is the northern extension of the Louisiana limestone, then the Chonopectus sandstone and the underlying shales would be included in the Devonian according to Keyes'* interpretation of the Kinderhook. The basis for his determination of the Devonian age of the Louisiana limestone, however, seems not to be well founded. The fact that in a single vertical section like that at Louisiana, including several diverse lithologic formations, a line can be drawn, above and below which there are no species of fossils in common, does not necessarily indicate a profound life break. From a broad point of view this is seen possibly to indicate only a change in local conditions such as to cause a shifting in the geographic distribution of life. In almost any geologic section of any considerable thickness, in which there are diverse lithologic formations, no matter to what geologic period it may belong, there may be found just such profound life breaks, but judgment must be used in the interpretation of these faunal changes.

It is not the writer's intention to positively deny the contemporaneity of a portion, perhaps a large portion, of the Kinderhook beds with some of the beds referred to the uppermost Devonian in other portions of the continent, but if any part of them are Devonian, the evidence of their age will have to be of a more substantial nature than that offered by Keyes. There are certainly Devonian elements in the fauna of the Louisiana limestone, but there also are conspicuous elements of Devonian life in some formations of the age of the St. Louis limestone,† and yet no one would insist for a moment on their Devonian age. The Chonopectus sandstone also possesses a strong Devonian element in some particulars, — it is far more strongly Devonian than the fauna of the Louisiana limestone, — but in both faunas there is another element of perhaps greater significance binding them to the Carboniferous.

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* Trans. Acad. Sci. St. Louis. **7** : 357. (1897.)

† Am. Jour. Sci. III. **49** : 94.

The composition of the Chonopectus sandstone fauna is as follows: —

CLASS.	GENERA.	SPECIES.
Brachiopoda	15	20
Pelecypoda	19	32
Gastropoda	12	21
Scaphopoda	1	1
Pteropoda	1	1
Cephalopoda	4	6
Total	52	81

Of these genera and species, the brachiopods are for the most part strongly Carboniferous in aspect. The abundance of *Productus* is particularly a Carboniferous characteristic of the fauna, as is also the presence of *Syringothyris*. Of the two species of *Spirifer*, one, *S. subrotundatus*, with its completely plicated shell and with the plications on the lateral slopes bifurcating, is strongly carboniferous in aspect, while *S. biplicatus*, on the other hand, with its excessively elongate hinge-line, has just as strong a Devonian aspect. The shell identified as *Schizophoria swallovi* is far more like the Carboniferous than the Devonian representatives of the genus. The presence of *Productella* may be considered as a Devonian element, and also *Orthothetes inaequalis*, which is so nearly like *O. chemungensis*.

The pelecypods have quite a different story to tell, and from a study of this portion of the fauna alone, one would perhaps be justified in identifying it as of Devonian age. All of the nineteen genera, with the exception of two, *Promacrus* and *Avicula*, have numerous representatives in the Devonian faunas of Eastern North America, particularly in the Chemung faunas of New York and Pennsylvania, and several of the genera have no representation later than Kinderhook. *Promacrus* is a genus which is represented in America only in faunas of Kinderhook age, and in Europe it has been noted only in Belgium from near the base of the Carboniferous. *Avicula* is in general a later genus. Not only are most of the genera of pelecypods abundantly represented in the Devonian, but in several instances the species in the Chonopectus sandstone are so nearly like species in the Chemung of New York, that it is largely a matter of personal opinion as to whether they are really distinct or not. These specific similarities have been pointed out in connection with the descriptions of the species.

The gastropods and cephalopods are also, for the most part, of Devonian types, with no strikingly Carboniferous characteristics. The genus *Agoniatites* has not previously been recognized outside the Devonian, and *Orthoceras whitei* is a very ancient type, being related to the Silurian *O. annulatum*.

Taken as a whole, a larger number of the total 81 species recognized in the fauna, have Devonian and not Carboniferous relationships, but this is not sufficient evidence upon which to establish the Devonian age of the fauna. In general, in paleontologic interpretation, the initiation of a new invertebrate faunal element is of greater importance than the holding over of a much larger element from an older fauna, and on this principle the strongly Carboniferous element among the brachiopods of the Chonopectus sandstone is to be considered as weightier evidence than the holdover pelecypods and cephalopods.

In the interior of the North American continent, the dividing line between the Devonian and Carboniferous periods is not sharply defined like that between the Ordovician and Silurian, for instance, but judging from the association of genera and species alone, the fauna under consideration, and indeed all the Kinderhook faunas, should be placed in the Carboniferous. However, if it can in any way be demonstrated that the strong Carboniferous element in the fauna had its point of origin right here in the Mississippi valley, and that these types of life existed here earlier than in any other part of the world, their presence in other regions being due to migrations of life from this region, then there may be some foundation for considering a part or the whole of the Kinderhook as being the very youngest Devonian. It yet remains to be demonstrated, however, whether or not the Kinderhook holds such a relationship to the Carboniferous of other parts of the world.

EXPLANATION OF ILLUSTRATIONS.

PLATES I.–IX.

(ALL OF THE FIGURES ARE OF NATURAL SIZE.)

Plate I. — 1–2, *Productus laevicostus* White. Pedicle and lateral views of an average specimen. U. of C. Coll., No. 5924. — 3–4, *Productus cooperensis* Swall.? Anterior and lateral views of a specimen identified as this species by A. Winchell. U. of M. Coll., No. 2000. — 5–6, *Productus semireticulatus* Martin. Lateral and anterior views of an average specimen. U. of M. Coll., No. 1336. — 7–8, *Productus semireticulatus* Martin. One of the type specimens of *P. curtirostris* Win., which proves to be the brachial valve of *P. semireticulatus.* U. of M. Coll., No. 1337. — 9–10, *Productella nummularis* (Win.). A pedicle and a brachial valve, two of the type specimens. U. of M. Coll., No. 1340. — 11–13, *Schizophoria swallovi* (Hall). The two larger specimens are a brachial and a pedicle valve. The smaller specimen is a pedicle valve which was used by Winchell as the type of *Orthis flava.* U. of M. Coll., Nos. 1351 and 2007. — 14, *Chonetes illinoisensis* Worthen. A somewhat distorted specimen. U. of C. Coll., No. 5925.— 15, *Chonetes* sp. undet. An imperfect impression of the brachial valve. U. of C. Coll., No. 5926. — 16, *Chonetes* sp. Cf. *C. geniculata* White. An internal cast of the pedicle valve. U. of C. Coll., No. 5927. — 17, *Chonopectus fischeri* (N. & P.). Illustration of an average pedicle valve. After Hall. — 18, *Orthothetes inaequalis* (Hall). A cast of a pedicle valve taken from a natural mould. U. of C. Coll., No. 5928. — 19, *Orbiculoidea capax* (White). The type specimen. U. of M. Coll., No. 1331. — 20, *Lingula membranacea* Win. The type specimen. U. of M. Coll., No. 1330.

Plate II. — 1–3, *Syringothyris extenuatus* (Hall). Anterior and posterior views of an average specimen. U. of C. Coll., No. 5929. A very large brachial valve. U. of M. Coll., No. 1365. — 4-5, *Rhynchonella* sp. undet. Two specimens showing the variation in form. U. of C. Coll., No. 5930. — 6–7. *Spirifer biplicatus* Hall. Views of a pedicle and a brachial valve, the pedicle valve preserving the mucronate extension of the hinge-line on one side. U. of C. Coll., No. 5931. — 8–10, *Spirifer subrotundatus* Hall. Pedicle, brachial and anterior views of an average specimen. U. of C. Coll., No. 5932. — 11, *Reticularia cooperensis* (Swall.). View of a brachial valve. U. of C. Coll., No. 5933. — 12–15, *Athyris corpulenta* (Win.). Views of two of the type specimens. U. of M. Coll., No. 1359. — 16–17, *Pugnax striatocostata* (M. & W.) var.? Pedicle and anterior views of an average specimen from the Chonopectus sandstone. U. of M. Coll., No. 1375. — 18–19, *Eumetria altirostris* (White). Brachia and pedicle views of a nearly perfect specimen. U. of C. Coll., No. 5934.

Plate III.— 1–2, *Pterinopecten* Cf. *P. laetus* H. A large, flat, right valve, and a smaller left valve. The left valve here illustrated was one of the types of *P. nodocostatus* (W. & W.). U. of M. Coll., No. 1390 and U. of C. Coll., No. 5935. — 3, *Aviculopecten tenuicostus* Win. One of the type specimens. U. of M. Coll., No. 1392. — 4, *Aviculopecten caroli* Win. One of the type specimens. U. of M. Coll., No. 1393. — 5, *Pernopecten* ? sp. This specimen may belong to *Posidomya ? ambigua* Win. U. of C. Coll., No. 5936. — 6-7, *Pteronites whitei* (Win.). Two of the type specimens. U. of M. Coll., No. 1384. — 8–9, *Leiopteria spinulata* (Win.). A left and a right valve, two of the type specimens. U. of M. Coll., No. 1382–1383. — 10, *Avicula strigosa* (White). One of the type specimens. U. of M. Coll., No. 1387. — 11, *Mytilarca occidentalis* (W. & W.) Left view of the type specimen. U. of M. Coll., No. 1400 — 12, *Mytilarca fibristriata* (W. & W.). Left view of the type specimen. U. of M. Coll., No. 1399. — 13–14, *Goniophora jennae* (Win.). Two of the type specimens. U. of M. Coll., No. 1428. — 15, *Macrodon cochlearis* Win. One of the type specimens. U. of M. Coll., No. 1422. — 16, *Macrodon modesta* (Win.). The type specimen U. of M. Coll., No. 1420. — 17, *Cypricardinia sulcifera* (Win.). One of the type specimens. U. of M. Coll., No. 1415. — 18, *Cardiopsis megambonata* Win. View of a left valve, not the type specimen. U. of M. Coll., No. 1429.

Plate IV. — 1–2, *Edmondia burlingtonensis* W. & W. Two of the type specimens. U. of M. Coll. No. 1405. — 3, *Edmondia aequimarginalis* Win. View of a left valve, not the type specimen. U. of M. Coll., No. 1408. — 4, *Edmondia nitida* Win. The type specimen. U. of M. Coll., No. 1406. — 5, *Edmondia jejunus* (Win.). One of the type specimens. U. of M. Coll., No. 1416 (in part). — 6, *Glossites elliptica* (Win.). The type specimen. U. of M. Coll., No. 1411. — 7, *Sphenotus iowensis* (Win.). The type specimen. U. of M. Coll., No. 1414 (in part). — 8, *Sphenotus bicostatus* n. sp. The type specimen. U. of M. Coll., No. 1414 (in part). — 9, *Sphenotus rigidus* (W. & W.). One of the type specimens. U. of M. Coll., No. 1417. — 10, *Sphenotus bicarinatus* (Win.). One of the type specimens. U. of M. Coll., No. 1410. — 11, *Glossites ? burlingtonensis* n. sp. The type specimen. U. of M. Coll., No. 1412 (in part). — 12, *Spathella ventricosa* (W. & W.). One of the type specimens. U. of M. Coll., No. 1402. — 13–14, *Schizodus iowensis* n. sp. The type specimens, a right and a left valve. U. of M. Coll., No. 1419 (in part). — 15, *Schizodus burlingtonensis* n. sp. The type specimen. U. of M. Coll., No. 1416 (in part). — 16, *Grammysia amygdalinus* (Win.). The type specimen. U. of M. Coll., No. 1412. — 17, *Edmondia quadrata* (W. & W.). One of the type specimens. U. of M. Coll., 1430. — 18–19, *Posidonomya ? ambigua* Win. Two of the type specimens. U. of M. Coll., No. 1430. — 20, *Promacrus cuneatus* H. View of the type specimen (after Hall). — 21, *Grammysia plena* H. View of a left valve (after Hall).

Plate V. — 1–2, *Porcellia crassinoda* W. & W. Lateral and dorsal views of the type specimen. U. of M. Coll., No. 1441. — 3, *Porcellia obliquinoda* White. Lateral view of the type specimen. U. of M. Coll., No. 1442. — 4–5, *Strophostylus bivolve* (W. & W.). — Two views of one of the type specimens. U. of M. Coll., No. 1444.

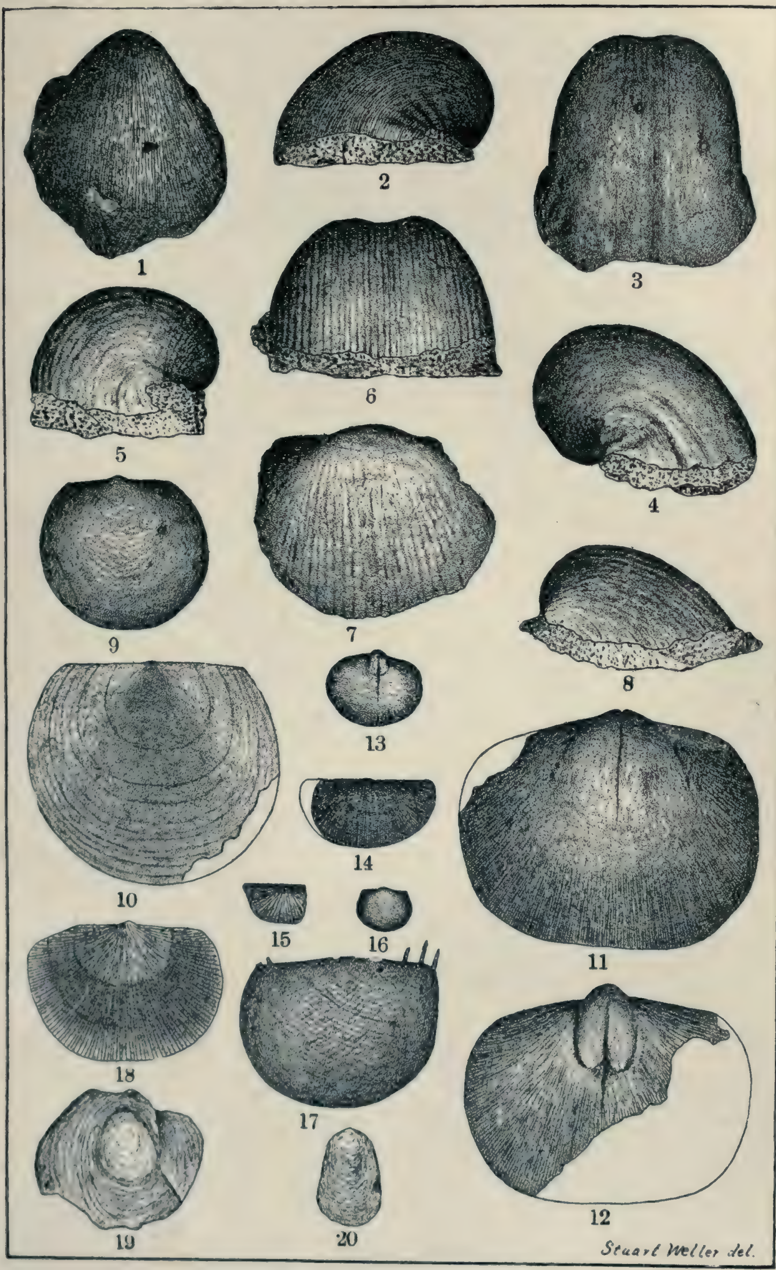
Plate VI. — 1–2, *Sphaerodoma pinguis* (Win.) Two views of the type specimen. U. of M. Coll., No. 1461. — 3-4, *Naticopsis depressa* Win. Two views of one of the type specimens. U. of M. Coll., No. 1464. — 5, *Bucanopis deflectus* n. sp. A dorsal view of the type specimen. U. of M. Coll., No. 1437 (in part). — 6, *Patellostium scriptiferus* (White). Dorsal view of the type specimen. U. of M. Coll., No. 1436. — 7–8, *Bellerophon panneus* White.? Two views of a specimen provisionally referred to this species. U. of C. Coll., No. 5937.— 9–10, *Bellerophon bilabiatus* W. & W. Two views of one of the type specimen. U. of M. Coll., No. 1438.— 11–12, *Bellerophon vinculatus* W. & W. Two views of an authentic specimen which may be the type. U. of M. Coll., No. 1440.— 13–14, *Straparollus angularis* n. sp. Two views of the type specimen. U. of M. Coll., No. 1454.— 15-16, *Platyschisma barrisi* (Win.). Two views of the type specimen U. of M. Coll., No. 1456 (in part).— 17–18, *Straparollus macromphalus* Win. Two views of the type specimen. U. of M. Coll., No. 1457.— 19–21, *Platyschisma depressa* n. sp. Three views of the type specimen. U. of M. Coll., No 1456 (in part). — 22, *Straparollus ammon* (W. & W.). View of a specimen supposed to be one of the types. U. of M. Coll., No. 1455.

Plate VII. — 1, *Phanerotinus paradoxus* Win. View of the type specimen. U. of M. Coll., No. 1458. — 2, *Loxonema* sp. U. of M. Coll., No. 1451. — 3, *Murchisonia quadricincta* Win. View of the type specimen. U. of M. Coll., No. 1450. — 4, *Loxonema oligospira* Win. View of the type specimen. U. of M. Coll., No. 1462. — 5, *Loxonema shumardana* (Win.). View of the type specimen. U. of M. Coll., No. 1453. — 6, *Dentalium grandaevum* Win. View of the type specimen. U. of M. Coll., No. 1447. — 7, *Conularia byblis* White. View of the type specimen. U. of M. Coll., No. 1432. — 8, *Agoniatites opimus.* (W. & W.). Lateral view of the type specimen of this species. U. of M. Coll., No. 1470. — 9, *Cyrtoceras unicorne* Win. Lateral view of the type specimen. U. of M. Coll., No. 1469.

Plate VIII. — 1, *Agoniatites opimus* (W. & W.). Lateral view of a very large specimen showing the sutures. Univ. of Ia. Coll.

Plate IX. — 1, *Agoniatites opimus* (W. & W.). Outline view of the specimen figured on Plate VIII, fig. 1, somewhat restored. — 2, *Phragmoceras expansum* Win. Lateral view of the type specimen. U. of M. Coll., No. 1468. — 3, *Orthoceras indianense* H. Lateral view of a fragmentary specimen. U. of M. Coll., No. 1465. — 4–5, *Orthoceras whitei* Win. Views of two of the type specimens. U. of M. Coll., No. 1466. — 6, *Orthoceras heterocinctum* Win. View of one of the type specimens. U. of M. Coll., No. 1467.

Issued February 24, 1900.



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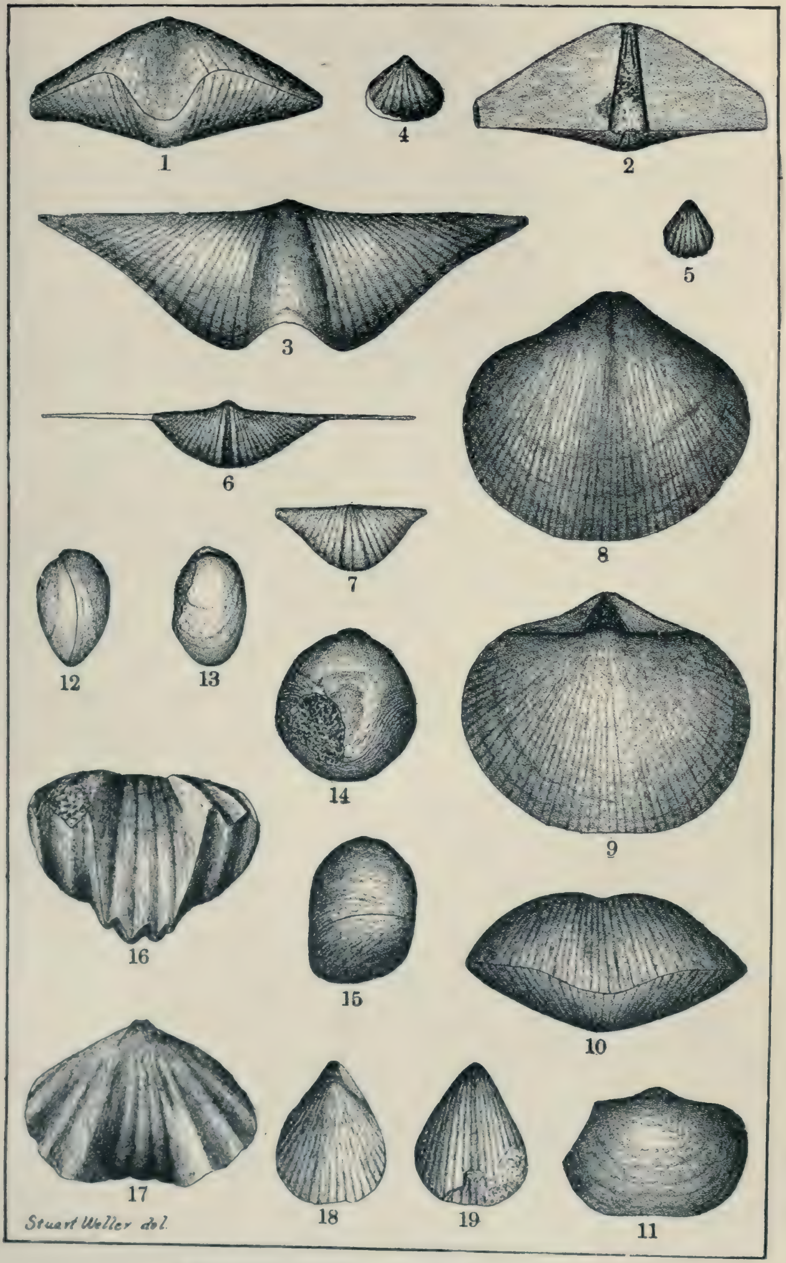

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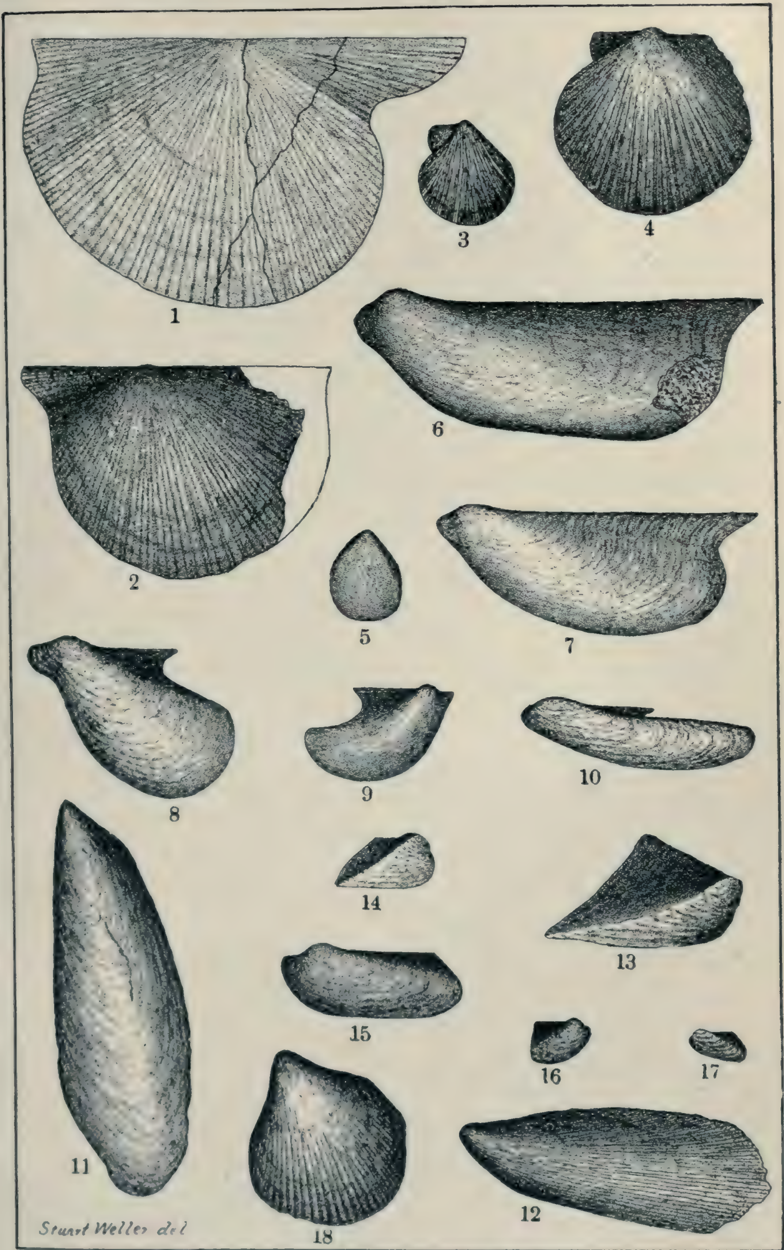

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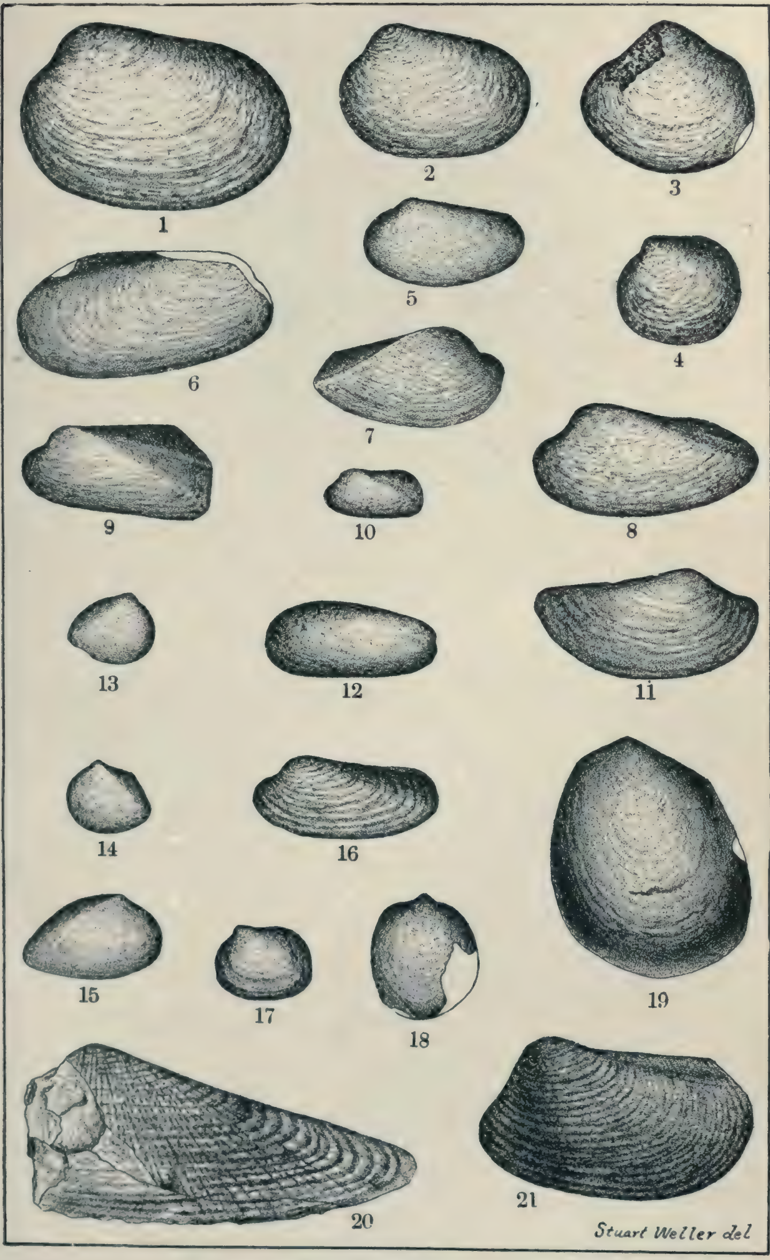

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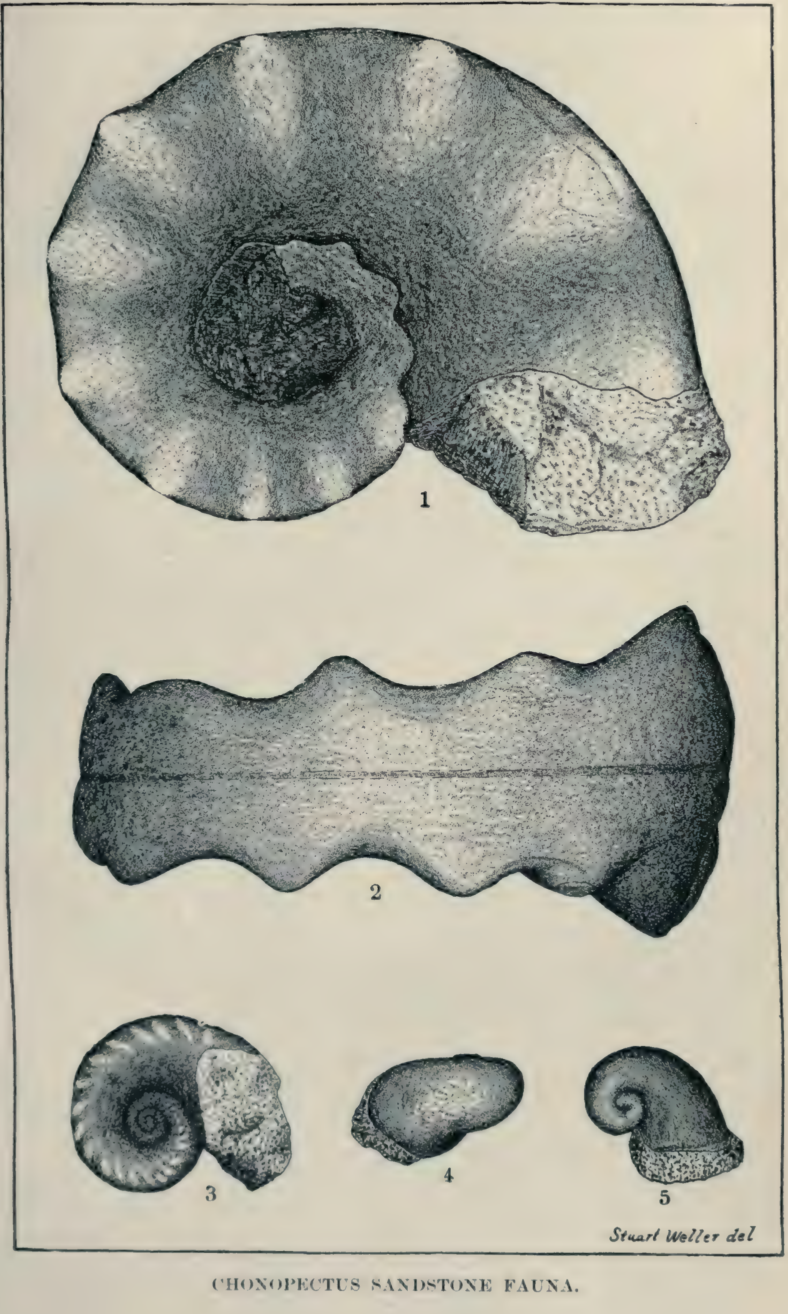

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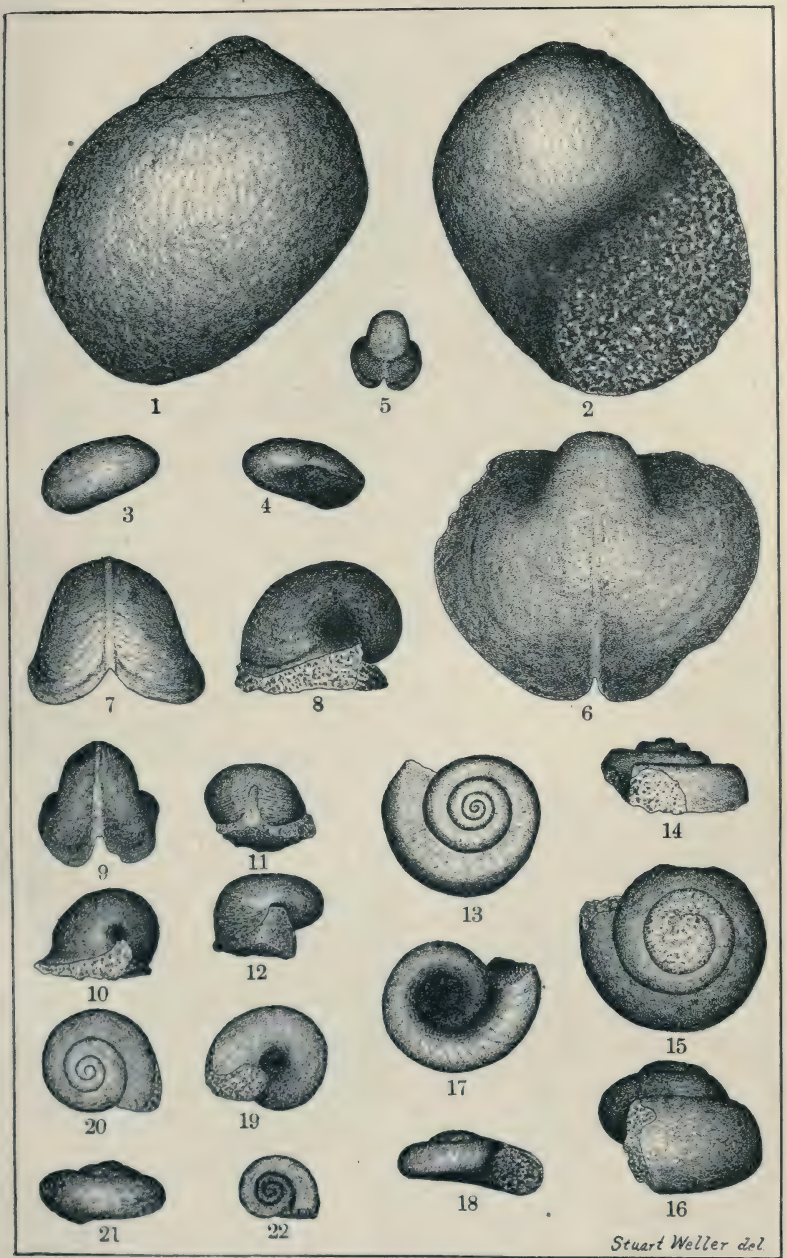

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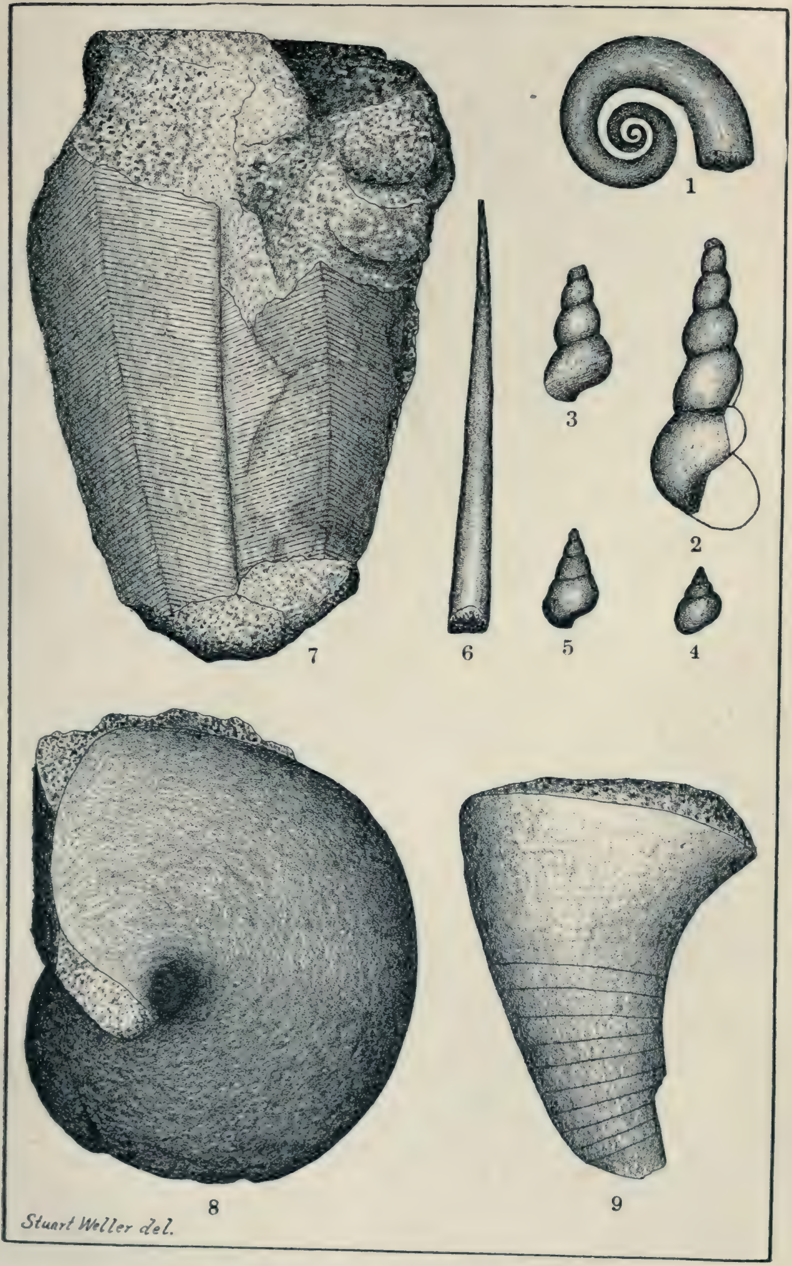

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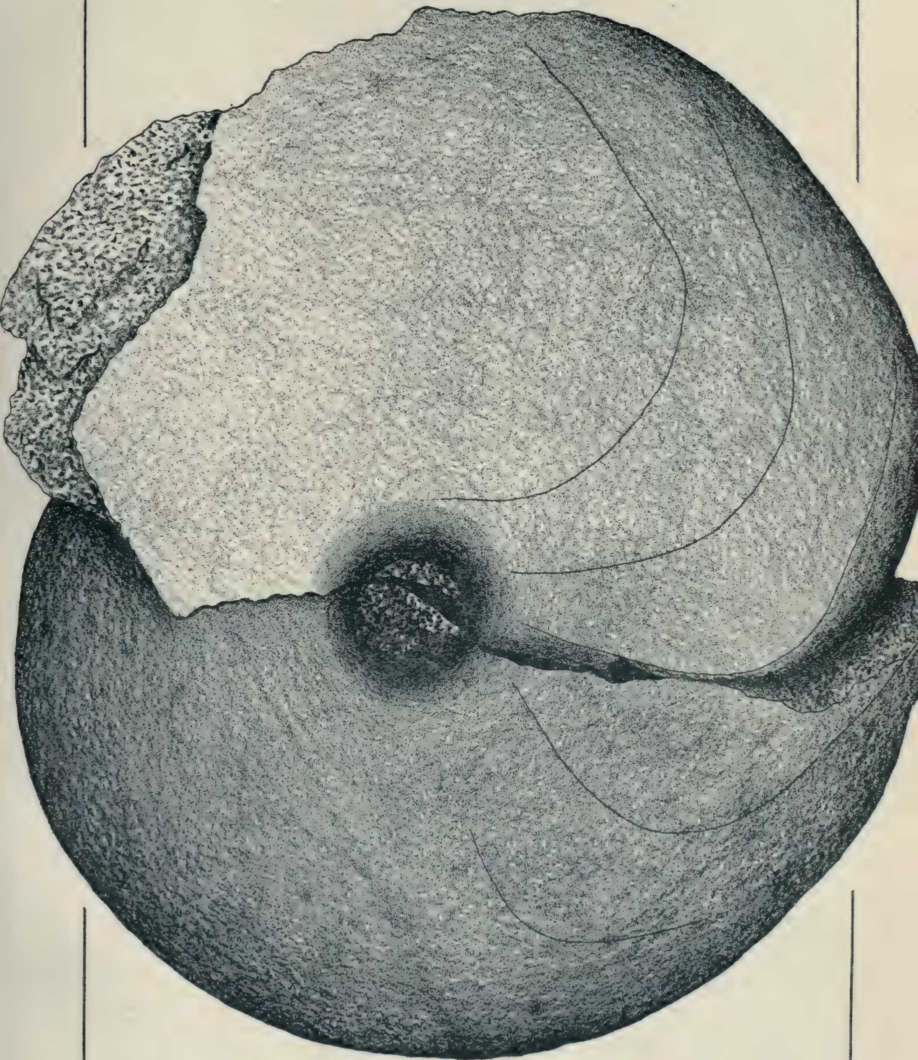

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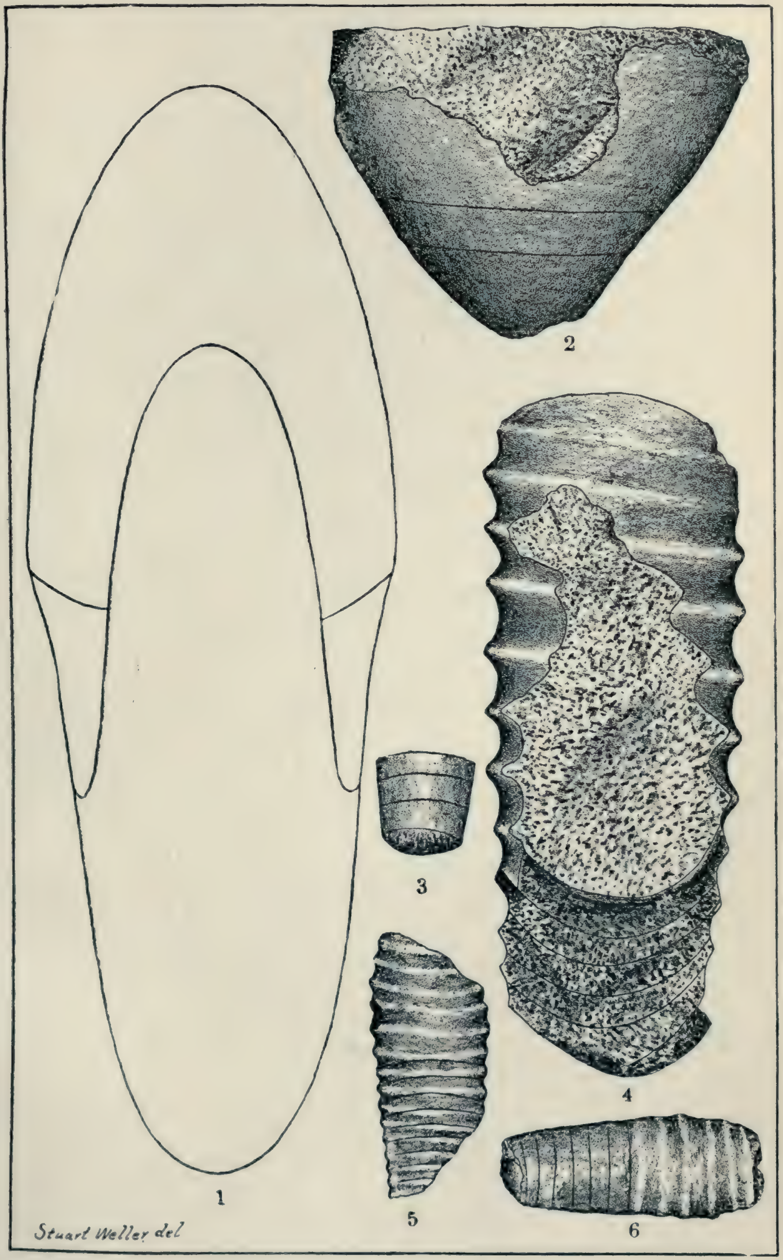

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STUDIES ON SUBTERRANEAN ORGANS. II. SOME DICOTYLEDONOUS HERBACEOUS PLANTS OF MANHATTAN, KANSAS.*

A. S. Hitchcock.

In the present article are discussed the underground parts of a number of perennial dicotyledonous, herbaceous, and several shrubby plants of the vicinity of Manhattan.

Some have already been mentioned, and figured in Bulletin 76 of the Experiment Station.

The plants are divided as in Article I,† into those forming crowns, those forming rhizomes or stolons, and those propagating by adventitious buds upon creeping roots.

Crown Formers. I have designated as a crown the persistent base of vegetative stems. The new stems hence arise as lateral shoots upon the base of a stem, the upper part of which died to the ground, or even below the surface. I have designated as a caudex a vertical rhizome. In this case the main axis is not a vegetative shoot but produces a terminal bud which continues the growth. A caudex advances slowly and is usually pulled down into the ground by contraction of the lateral roots about as fast as it grows upward, hence does not extend above the surface. The crown may be formed upon a fleshy or thickened root, in which case the chief portion of the underground part is root, or it may be supported by fibrous or small woody roots in which case the chief portion of the underground part is stem. In the first series the root may be very large as in *Oxybaphus nyctagineus*, *Phytolacca decandra*, and *Cucurbita foetidissima*. In more numerous cases the root is smaller but distinctly fleshy, as *Callirrhoe involucrata*, and *Asclepiodora viridis*. In *Psoralea esculenta*

* Presented in abstract, with illustrative specimens, to The Academy of Science of St. Louis, March 5, 1900.

† Trans. Acad. Sci. of St. Louis, 9 : 1.

it is spherical with a slender prolongation below and a slender crown above. *Asclepias stenophylla*, *Polytaenia Nuttallii* and others have a slender fleshy root. The first has a rhizome-like crown and the other is surmounted by a caudex. Sometimes the crown branches and there are several small crowns tracing back to the same root. In several cases, *Lithospermum hirtum*, *Astragalus caryocarpus*, and *Petalostemon*, the root is thick and woody rather than fleshy, while the top forms a compact crown.

In the second series, the simplest case is that of a small tap-root extending upward into a single vegetative stem the first year. The second season vegetative shoots arise from buds at the base of this stem. If the plant is long lived the crown thus formed becomes thicker and thicker from year to year. *Verbena* and *Nepeta Cataria* are examples. If a mass of fibrous roots is produced instead of a tap-root a crown of a different nature is produced. In most cases the older portion below dies off and the crown is thus relatively small. Examples are *Ruellia ciliosa* and *Asclepias incarnata*. The base of the vegetative stem may be oblique or decumbent, in which case the new stems often appear as offsets along the base and become independent at an early date, as *Pentstemon Cobaea*. In *Penthorum sedoides* autumn rosettes are produced which elongate the following spring. There is a transition from such oblique offsets to short rhizomes.

Propagation by Stolons. Here are included those species which propagate by means of stems above ground rooting and thus forming independent plants. *Symphoricarpos vulgaris* forms prostrate leafy branches for this purpose while *Fragaria Virginiana* forms the familiar runners and *Rubus occidentalis* roots at the tips of the recurved branches.

Propagation by Rhizomes. There are all gradations from the oblique branches from a crown to the extensive rhizomes of *Rumex venosus* and *Laportea Canadensis*. The upright rhizome or caudex has been mentioned as occurring at the summit of a fleshy root. Often it is the chief underground portion, bearing lateral fibrous roots. There is a transition from the vertical caudex through the oblique caudex to the slowly creeping horizontal rhizome such as *Thalictrum pur-*

purascens, and *Agrimonia mollis*. The familiar *Polygonatum giganteum* is the typical form of this. The upper part of the oblique caudex is drawn down into a horizontal position each successive year by the contraction of the lateral roots. At first the oblique crown and the oblique caudex may seem to resemble each other. The oblique crown is surmounted by the dead base of a vegetative stem or else, where offsets are produced which soon become independent, the old stem disappears. But the oblique or slowly creeping horizontal rhizome ends in a terminal bud which continues the growth. The vegetative stems are thus axillary from the rhizome.

The creeping rhizome may show peculiarities, as in *Teucrium Canadense*, where it is dorsiventrally flattened and constricted at the nodes. In *Scutellaria parvula* the internodes, or some of them, swell up into so-called tubers, forming a more or less interrupted chain, "subterranean stolons moniliform-tuberiferous," Gray. In *Apios tuberosa* genuine tubers are formed though they are not usually terminal on a rhizome as is the common potato, but there may be several on one rhizome. These tubers may send out new rhizomes or may become a crown and send up successive vegetative shoots. *Glycyrrhiza lepidota* produces deep root-like rhizomes which may grow several or many feet before producing a new plant. Each new plant becomes a strong crown. One would scarcely suspect the presence of rhizomes in this case.

Comandra pallida propagates in a similar manner but the crowns are closer together. *Astragalus Plattensis* is also similar but the new plant forms a small fleshy root below and sends a stem to the surface which becomes a small or slender crown. *Ipomoea leptophylla*, a very peculiar case, was described in the Botanical Gazette, **25**: 52. This plant forms a very large fleshy root, the summit of which is sunken several inches below the surface. A crown is formed but in addition it propagates by slender roots about the size of a fence wire which have their origin along the lower half of the root and rise obliquely to near the surface when the new plant is formed several feet from the parent. In some plants the creeping decumbent bases of the vegetative shoots branch and root abundantly, forming a tangled mass of stems which persist through the winter and send out new branches in the spring; such are *Lycopus sinuatus*, *Lippia lanceolata* and *Dianthera Americana*.

Propagation by Adventitious Buds upon Creeping Roots. Creeping roots of the typical form are produced by *Rhus glabra*, *Ambrosia psilostachya*, *Cnicus undulatus*, *Apocynum cannabinum*, *Enslenia albida*, *Convolvulus arvensis*, and *Rumex Acetosella*, some of which are, on this account, bad weeds. *Asclepias Cornuti* has a thick oblique root producing buds along its surface. Sometimes the new plants thus produced form a crown as in *Ascelepias verticillata*.

Solanum Carolinense and several species of *Physalis* have a very deep slender vertical or horizontal root. Shoots may start from this at considerable depth, and may become slender crowns, thus giving the impression that the plant propagates by rhizomes.

As to the relation between underground parts of plants and their habitat little can be said. On the stony hills, crown formers are the rule. Species with rhizomes (*Comandra pallida*) and creeping roots (*Rhus glabra*) are rare. Even in these cases crowns are also formed. Rhizomes are not produced on prairie species to any great extent but rather on our mesophyte species inhabiting the rich loam of our woods or moist places along streams and sloughs. All kinds are found about equally in the sand-hills. Of course the perennial weeds of cultivated soil are those producing rhizomes or creeping roots rather than the crown formers.

Clematis Pitcheri, Torr. & Gray. A woody vertical crown several inches long covered with fibrous roots. Moist thickets.

Anemone decapetala, L. Vegetative stems arise from small tubers. After flowering, the tubers send out slender white rhizomes which form tubers at the apex. These tubers produce the vegetative stems of the following spring. Prairie.

Anemone Virginiana, L. A slowly creeping oblique rhizome. Open woods.

Thalictrum purpurascens, L. A slowly creeping rhizome, only one-half to one inch long. A strong bud is produced just beyond the base of the vegetative stem. Low prairie or open woods.

Delphinium azureum, Michx. A crown from a cluster of fascicled roots. Prairie.

Helianthemum Canadense, Michx. New stems from base of old. Upland woods.

Lechea tenuifolia, Michx. A small but strong tap-root supporting a crown of small stems. Upland woods.

Viola pedatifida, Don. A vertical or oblique caudex. Prairie.

Silene stellata, Ait. Rather strong root with dichotomously branched crown. Open woods.

Callirrhoe involucrata, Gray. A spindle-shaped fleshy root an inch or more thick, from the sunken summit of which the vegetative stems arise. Prairie.

Oxalis corniculata, L. A tap-root with a crown but the decumbent bases of the stem may root more or less. Open ground.

Oxalis corniculata, L. var. *stricta*, Sav. Filiform rhizomes. Moist soil.

Ceanothus ovatus, Desf. Woody root with strong crown. Prairie and stony hills.

Rhus glabra, L. Creeping roots which produce buds. Thickets and stony hills.

Rhus Toxicodendron, L. Rhizomes which creep just below the surface. Woods and fence rows.

Baptisia leucophaea, Nutt. A horizontal woody more or less branched rhizome with strong lateral roots. Prairie.

Baptisia leucantha, Torr. & Gray. A thick woody slowly-creeping rhizome forming a crown at the apex. Moist meadows.

Baptisia australis, R. Br. A woody root surmounted by a thick short knotty horizontal crown. New buds forming at base of old stem. Prairie.

Psoralea floribunda, Nutt. A strong vertical fleshy root, often branched below. Several stems arise from the summit which is several inches below the surface. Prairie.

Psoralea argophylla, Pursh. A long woody or somewhat fleshy tap-root sunken several inches below the surface. From the crown at apex, one or more slender vegetative stems are sent up. Prairie.

Psoralea lanceolata, Pursh. Stems erect from large creeping rhizomes. Sand-hills.

Psoralea esculenta, Pursh. A globose woody-fleshy sunken root, well stored with starch, abruptly tapering into a slender tap-root. An elongated crown reaches to the surface and bears buds along the side. Prairie.

Amorpha canescens, Nutt. Similar to the next. Forms a knotty crown. Prairie.

Amorpha fruticosa, L. Woody root. No vegetative propagation. Moist places.

Petalostemon violaceus, Michx. *P. candidus*, Michx. *P. multiflorus*, Nutt. All produce a thick woody root, supporting a large crown with numerous stems. First occurs on prairie and stony hills; the second mostly on prairie; the third is confined to limestone hills.

Astragalus caryocarpus, Ker. Crown of nearly upright stems at surface of ground, supported by a strong more or less branched tap-root. Prairie.

Astragalus Plattensis, Nutt. Slender creeping rhizomes which establish plants at intervals of two to six inches. Each such plant forms a slender tap-root, below the rhizome, while each stem may form a crown at the surface. Prairie.

Astragalus lotiflorus, Hook. A tap-root forming a crown at summit. Limestone hills.

Glycyrrhiza lepidota, Nutt. Root-like rhizomes creeping several feet before establishing plants. Each plant produces a crown and also sends out a few rhizomes. Moist prairie.

Desmodium acuminatum, DC. A slender deep, sunken root at the apex of which arise a stem made up of a series of progressively younger portions toward the surface. Upland woods.

Desmodium canescens, DC. A strong woody crown. Open woods.

Desmodium sessilifolium, Torr & Gray. Tap-root with crown. Prairie.

Lespedeza violacea, Pers. A slender tap-root with crown of numerous slender stems. Upland woods.

Lespedeza capitata, Michx. Crown upon a strong woody root. Prairie.

Vicia Americana, Muhl. Slender rhizomes. Prairie.

Lathyrus ornatus, Nutt. Extensive, slender, branching, horizontal rhizomes, more or less winged like the stem. Sand-hills.

Apios tuberosa, Moench. Rhizomes which enlarge into tubers at intervals of an inch or so, or even several inches. The tubers send out new rhizomes and also may produce vegetative stems, near the end. Shoots may arise in successive years from the same tuber. Moist thickets and low ground.

Cassia Marylandica, L. Forms a crown. Low ground.

Desmanthus brachylobus, Benth. A thick, woody tap-root supporting a large crown. Low ground.

Schrankia uncinata, Willd. A vertical, woody, sunken root, surmounted by one or more woody, knotty stems, from the summit of which grow the several slender vegetative stems. Prairie.

Prunus Watsoni, Sarg. Roots produce buds abundantly. Sand-hills.

Geum album, Gmelin. A slowly creeping oblique rhizome about an inch long. Flowering stems axillary. New bud terminal at base of vegetative shoot. Woods.

Agrimonia mollis, Britt. A slowly creeping rhizome, the new plant just beyond the old. Woods.

Agrimonia parviflora, Ait. Offsets formed at base of old stem. Woods.

Rosa Arkansana, Porter. Extensive rhizomes. Prairie.

Penthorum sedoides, L. Base decumbent and rooting. In the autumn rosettes or offsets are produced, which elongate into vegetative shoots the following spring. Wet places.

Lythrum alatum, Pursh. New stems arising from the base of old. Moist places.

Ludwigia alternifolia, L. Forms buds at base of old stem. Springy places.

Oenothera Missouriensis, Sims. A fleshy-woody sunken root throws up one or more stems each of which forms a crown at the surface. Limestone hills.

Oenothera serrulata, Nutt. A woody crown, forming buds along the base of the old stem. Prairie.

Stenosiphon virgatus, Spach. A strong tap-root with a crown. The bases of the stems persist above ground more or less, and form winter buds. It is thus a semi-shrub. Limestone hills.

Circaea Lutetiana, L. Slender rhizomes. Rich woods.

Opuntia Rafinesquii, Engelm. Forms a tap-root. The first joint throws out lateral joints, and these may root where they come in contact with the soil. Joints mostly perennial. Sand-hills.

Polytaenia Nuttallii, DC. A fleshy vertical root surmounted by a caudex marked with a series of close rings or leaf-scars. Prairie.

Peucedanum foeniculaceum, Nutt. One or more caudices from a sunken vertical fleshy root. Stony hills.

Cicuta maculata, L. A fleshy caudex surmounting a fleshy root which is an inch or two long and half an inch thick, and branched below into several fleshy tuber-like portions. Wet places.

Sanicula Marylandica, L. A short caudex. Woods.

Cornus asperifolia, Michx. Woody rhizomes. Woods and thickets.

Sambucus Canadensis, L. Thick rhizomes. Low woods.

Triosteum perfoliatum, L. A slowly creeping woody rhizome or knotty crown. Open woods.

Symphoricarpos vulgaris, Michx. An ordinary shrubby root and crown but propagates by long leafy runners or prostrate stolens, which creep along the surface for a few feet and strike root, forming a new plant. Woods.

Galium circaezans, Michx. A small crown, with a few fibrous roots. Woods.

Galium trifidum, L. var. *latifolium*, Torr. The slender, decumbent, rooting bases of the stems resemble rhizomes. Woods.

Galium triflorum, Michx. A crown of tangled stems which throws out buds and fibrous roots. Woods.

Apocynum cannabinum, L. Buds upon extensively creeping horizontal roots. Moist soil.

Asclepiodora viridis, Gray. A thick woody-fleshy vertical or oblique root supporting a strong crown. Prairie.

Asclepias tuberosa, L. A strong woody or slightly fleshy, vertical or oblique root, with crown at summit. Prairie.

Asclepias incarnata, L. A small crown with a dense cluster of slender fibrous roots. Wet places.

Asclepias Cornuti, DC. Produces buds upon the roots but not abundantly. Usually there is a long oblique or horizontal main root with several stems growing from it, each of which may become a crown. Moist places.

Asclepias verticillata, L. Roots produce buds. Also a crown is formed at the base of the old stem. Prairie.

Asclepias stenophylla, Gray. A few inches below the surface is a slender, fleshy root a few inches long and half an inch thick which ends abruptly in a long, slender tap-root. A vertical rootstock extends to the surface where a crown may be formed. Prairie.

Enslenia albida, Nutt. Buds upon creeping horizontal or vertical root. Moist soil.

Lithospermum hirtum, Lehm. Tap-root with crown. Sandhills.

Lithospermum canescens, Lehm. A slender branched, woody root supporting a slender crown. Prairie.

Lithospermum angustifolium, Michx. A slender fleshy vertical root about half an inch in diameter. Buds from sunken summit or from base of old stem. Prairie.

Onosmodium Carolinianum, DC. var. *molle*, Gray. A woody crown upon a woody tap-root. Prairie.

Convolvulus Sepium, L. Rhizomes creeping a few inches to two feet below the surface. Moist places.

Convolvulus arvensis, L. Buds upon slender, creeping roots. The roots may be several inches below the surface and send up stems which produce buds along the underground portion thus giving the impression that the plant propagates from rhizomes. A weed in cultivated soil.

Solanum Carolinense, L. Root slender and usually extending vertically to a depth of four or five feet. Stems are produced above from adventitious buds. Open ground.

Physalis Virginiana, Mill., *lanceolata*, Michx., *longifolia*, Nutt. In the three species studied there is a deep-seated slender root similar to *Solanum Carolinense*. In old plants the stem portion extends to considerable depth and is variously branched. The new stems may come from rhizomes or from the roots. Prairie or sandy soil.

Pentstemon Cobaea, Nutt. A creeping rhizome which is a crown rising obliquely to the surface, bearing numerous lateral roots. Limestone hills.

Pentstemon grandiflorus, Nutt. Base of stem decumbent, throwing up offsets. Sand-hills.

Ruellia ciliosa, Pursh. Small crown with a fascicle of fibrous roots. Prairie.

Dianthera Americana, L. Extensive creeping white rhizomes about the size of the vegetative stems, rooting at the nodes. The lower part of the stem roots at the nodes and persists. The vegetative stems are thus a continuation of the upturned ends of the rhizomes. In water or very wet places.

Verbena urticaefolia, L. Tap-root with small crown. Low ground.

Verbena hastata, L. Tap-root with strong crown. Low ground.

Verbena stricta, Vent. A tap-root supporting a crown. Prairie.

Lippia lanceolata, Michx. Extensively creeping intertwining rhizomes similar to the vegetative stems, rooting at the nodes. Wet places.

Teucrium Canadense, L. Creeping rhizomes with distinct dorsiventrally flattened internodes. Thickets and moist places.

Lycopus sinuatus, Ell. Creeping rhizomes with distinct internodes rising obliquely into the vegetative stem. Rooting at nodes. Wet places.

Pycnanthemum muticum, Pers. var. *pilosum*, Gray. Short rhizomes which soon become erect, thus producing stems in clusters. Springy bogs.

Salvia azurea, Lam. var. *grandiflora*. Benth. A strong crown with woody roots. Prairie.

Monarda fistulosa, L. Slender brown woody rhizomes, extensively interlacing. Thickets and open woods.

Lophanthus nepetoides, Benth. A crown with numerous fibrous roots. Woods.

Nepeta Cataria, L. A strong crown.

Scutellaria lateriflora, L. Slender white square rhizomes with long internodes, and small scales. Wet places.

Scutellaria parvula, Michx. Creeping moniliform rhizomes. The internodes swell up into tuber-like bodies. Moist sandy soil.

Brunella vulgaris, L. Small crown. New plants forming at base of old stems. Moist places.

Leonurus Cardiaca, L. Similar to *Nepeta*.

Plantago Rugellii, Dec. A thick cylindrical caudex, with leaves from the upper portion and fibrous roots below. Woods.

Plantago lanceolata, L. A tap-root supporting a branched, short-lived crown. A weed in meadows.

Oxybaphus nyctagineus, Sweet. A strong fleshy tap-root which may extend three or four feet below the surface. The new shoots form at the base of the old ones or at various places along the side of the root, near the top. Open ground.

Oxybaphus angustifolius, Sweet. A long slender vertical root surmounted by knotty somewhat sunken crown. Prairie.

Phytolacca decandra, L. Forms a large fleshy tap-root which frequently branches. New stems form at the crown on the summit which is a short distance below the surface. Moist woods and barnyards.

Rumex Patientia, L., *altissimus*, Wood, *crispus*, L. A fleshy somewhat branched tap-root supporting a crown. Moist places.

Rumex venosus, Pursh. Extensive rhizomes often reaching to considerable depth. Sandy soil.

Rumex Acetosella, L. Buds on slender creeping roots. A weed in fields.

Polygonum Muhlenbergii, Wats. Extensive rhizomes. Moist soil.

Polygonum Virginianum, L. Small woody crown. Low woods.

Comandra pallida, A. DC. Root-like rhizomes, which produce plants at intervals, each plant forming a crown, that throws up one or more shoots each year. Stony hills.

Euphorbia corollata, L. A slender black vertical root surmounted by one or more caudices. Prairie.

Humulus Lupulus, L. Crown supported by a rather strong root. Thickets.

Urtica gracilis, Ait. Rhizomes. Low ground.

Laportea Canadensis, Gaud. Extensive tender white rhizomes about the size of the stems. Low woods.

Boehmeria cylindrica, Willd. A matted crown of stem bases. Rhizomes are formed which soon become upright stems. Low ground.

Following are a few additional notes on *Compositae**: —

Hymenopappus corymbosus, Torr. & Gray. This is biennial instead of perennial as stated in Article I.

Senecio aureus, L. var. *Balsamitae*, Torr. & Gray. A small caudex. Stony hills.

Cacalia atriplicifolia, L. Slowly creeping rhizome. Woods.

Cacalia tuberosa, Nutt. A caudex with fascicled roots. Low prairie.

Hieracium longipilum, Torr. Perennial by basal buds which produce rosettes in the fall or spring. Prairie.

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* See Trans. Acad. Sci. of St. Louis. **9**: 1.

A SEVERE SLEET-STORM.*

HERMANN VON SCHRENK.

During the evening and night of February 27th, a sleet-storm of unusual severity occurred over a large tract of country including parts of Missouri, Illinois, Indiana and Ohio. Sleet-storms of this kind occur with more or less regularity throughout the northern United States, whenever a southern storm center with rainclouds meets with freezing temperatures. The falling rain is not cooled sufficiently to turn to snow, and reaches the ground as rain. Here it freezes, and covers every object with a layer of ice. Generally this ice layer is very thin, and vanishes the next day. Occasionally, however, the conditions are favorable to the formation of thick ice, and the destruction which is then wrought to trees and shrubs is great.

Accounts of such storms have appeared now and then. Nipher † describes one of unusual severity which caused widespread destruction to trees in Missouri, on the nights of Feb. 19th and 20th, 1882. Some six inches of rain fell at that time. He says of this storm: "The enormous loading of the trees resulted in immense destruction of fruit and ornamental trees. * * * At Pleasant Hill, the weighing of ice-covered branches led to the result that a cedar tree 10 ft. high and with branches spreading at the base, had received over four hundred pounds of ice. * * * The damage occurred over an area of almost 5,000 square miles."

In Europe these ice-storms are apparently not as common as with us. Fischer ‡ mentions a number of notable storms which occurred in the Harz mountains from 1827–1875. He states that the weight of ice on the trees is often fifty pounds on six pounds of wood. A spruce tree 3½ ft. high had to support 165 lbs. Jamin§ describes a most extensive storm

* Presented in abstract to The Academy of Science of St. Louis, April 2, 1900.

† Nipher, F. E. Trans. St. Louis Acad. of Science. **4**: lxxii. 1882.

‡ Fischer, W. R., in Schlich's Manual of Forestry. **4**: 493. 1895.

§ Jamin, J. Le Verglas du 23 Janvier. Revue des Deux Mondes. **31**: 922. Feb. 15, 1879.

which occurred in France on Jan. 24, 1879, where some 50% of the wood was broken. He states among other things that a branch of Rhododendron weighing 13 grams bore a load of 360 grams of ice, and that an oak 2 meters in circumference was bent to within 4 m. of the ground. Plowright * tells of a similar storm which swept over portions of England on Jan. 7th, 1889. He figures an oak tree showing broken branches.

The storm of Feb. 27th began late in the afternoon. The maximum afternoon temperature was 29.2° F. Towards evening the temperature fell to 27.2° F. at 7 p. m. and reached a minimum of 26.6° F. during the night. The rainfall of Feb. 27th up to 7 o'clock was .36 inch. During the night 1.07 inches fell. About 8 o'clock it began to rain: the water froze as soon as it fell, and by the next morning a heavy coating of ice covered the trees, which were bent to the ground in many places by the load. The temperature of Feb. 28th remained below freezing (min. 24.2° F., max. 30° F.), likewise on the succeeding days,† and not until March 4th did any of the ice melt. By March 6th it had all disappeared.

The destruction brought about by the ice was very great, but considering the enormous weight which rested upon the branches, it is astonishing that it was not greater. The downward pressure exerted by the ice is oftentimes but one of the factors which cause a branch or trunk to break. The wind is of as great importance if not more so. A branch heavily weighted will bend far from its normal position without breaking, but if it is swayed back and forth violently the chances that it will break are almost doubled. Branches are very much more brittle when frozen, and a blow which would not affect a branch ordinarily will cause it to snap off when frozen, particularly if weighted with ice. Thus it is, that

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* Plowright, C. B. Notes on Hoar Frost. Jour. Roy. Hort. Soc. **13**: 117. 1891; also Gardener's Chronicle III. **5**: 459. 1889.

† The temperatures were: —

	Max.	Min.		Max.	Min.
March 1	33°	26°	March 4	52°	35°
2	34°	27°	5	58°	34°
3	40°	29°	6	60°	28°

The writer is indebted to Dr. R. J. Hyatt of the St. Louis Weather Bureau for the meteorological data.

ice-laden trees break so much more readily when the wind blows than on a still night, a fact familiar to most people. The wind velocities were not high during the storm period and on the following day. At 7 p. m. of Feb. 27th, it was 20 miles E., dropping to 17 miles during the night, and 14 miles N. by the morning of Feb. 28th. The extreme velocity on Feb. 28th was 31 miles N.

How great the weight was which was borne by the branches can perhaps best be seen from the accompanying photographs (upper figures, Pl. X, XI.), made on the morning of February 28th. The first one represents a group of hornbeam trees (*Carpinus betulus*) in the arboretum of the Missouri Botanical Garden; the second is a view on Flora avenue, a street extending east and west from the Garden (the photograph was taken looking to the east). The branches of the hornbeams trailed on the ground, and the tops of the small maple scraped on the snow of the street. It was impossible for one person to lift the top of the maple, much less to restore it to its original position. These trees are good instances of the appearance of the trees all over the affected area.

Some 200 branches, taken from various trees, were weighed, when covered with ice, and after the same had melted, to determine what weights the trees were able to withstand. Some of the results are given in the accompanying table. Something must be said about the distribution of the ice on the branches, before referring to the table. Vertical branches became coated with a layer of ice of equal thickness on all sides. After a time as the rain fell on the ice-coated twig, it flowed down and as the wind swayed the twig back and forth more ice was deposited at some points than at others. A thicker layer formed on the side from which the storm came; in some cases this was twice as thick as on the opposite side. If the branch was a strong one it bent but slightly under this added weight, and by the next morning it appeared as a long rod coated with a layer of ice varying from $\frac{3}{8}$–$\frac{7}{8}$ inches in thickness, in some cases even more. The great majority of branches are not vertical, but are inclined one way or another. The rain fell on the upper side and froze in part, while some dripped from the under side; the drops froze and formed long icicles, often one for every inch. Under this weight the branches drooped more and more; the strongest branches were bent to the ground, and in many instances the weight was great enough to break the branch. The smaller branches where the weight of ice was proportionately greatest often pointed vertically down to the ground. The rows of icicles then were almost horizontal.

Adjacent branches came to touch their neighbors and in a short time a mass of ice joined them one to the other. By moving one branch one could move the whole tree, one way or the other, as if it were one solid piece. This was particularly true of the conifers, where the opportunity for forming a solid coating of ice was so much more favorable. Such an ice-coated tree, when moved by the wind, moves as a mass, and breaks with incomparably greater ease than a tree in which each branch acts for itself, and can give way before the wind pressure.

Trees.	A. Branch with ice. Grams.	B. Branch without ice. Grams.	Ratio of A. to B.	Remarks.
Acer dasycarpum.......	132	17.5	7.5	
"	116	4.5	26.8	With icicles.
"	52	5.5	9.5	
"	206	24	8.9	
Ulmus Americana.......	2121	157	13.5	With icicles.
"	374	48	7.8	
Malva sp.	420	26	16.1	With icicles.
Malva "	307	37.5	8.1	Upright branch.
Peach (Prunus persica).	69	2	34.5	With icicles.
" .	35	2.5	14.	
" .	20	2	10	
" .	1322	98	13.5	Larger branch.
" .	1540	108	14.2	Larger branch.
Platanus occidentalis...	285	18	15.8	With icicles.
Thuja occidentalis......	325	23	14.1	
Pinus austriaca.........	608	35	17.3	
" "	510	27	18.8	
" "	275	18	15.3	
Viburnum sp...........	65	5	13	With icicles.
"	55	8	6.87	
"	19	3.5	5.4	
Pinus strobus...........	154	6	25.7	
"	316	22	14.3	
"	145	7	20.7	
Tsuga canadensis.......	755	22	34.3	
" "	1120	33	33.6	

In weighing the branches short pieces were taken; usually the twigs were about three years old, although several were older branches. It would obviously be unfair to compare a branch $\frac{1}{4}$ inch in diameter with one 2 inches in diameter, both covered with the same thickness of ice. The branches weighed were about 2 feet long and $\frac{1}{4}$ inch in diameter. The figures in the table must be considered as purely relative; they are intended to show merely that the weight borne by the smaller branches was a very large one, and to give some idea of the amount which three-year-old branches can bear without breaking.

From the table it appears that different twigs had different amounts of ice, as was to be expected, for no two twigs are alike in form or position. Twigs on the outside of a tree had more ice to bear than those more or less protected on the inside. The twigs with icicles usually bore twice as much ice as those without. The deciduous trees had approximately similar amounts to bear; the differences in the table are to be accounted for by differences in position. The coniferous trees had greater weights of ice than the others. The closely packed leaves of these trees were frozen into solid masses, making a most picturesque sight. The ice-mass steadily increased, because of the large surface exposed to the rain. The small branches of such trees as pine and hemlock had an unusually heavy weight to carry, and were bent, oftentimes so as to hang vertically. The hemlock had the greatest weight to bear, followed closely by the white pine.

The weight of the smaller branches had to be borne by the larger ones, and where these were not very flexible they broke off at the weakest point. There was no regularity as to the point at which the break occurred; it took place near the insertion of a branch and at all points towards the periphery of a tree. Knots and old wounds, made by the tornado of 1896, were the weak spots. A fine birch in the Botanical Garden, whose trunk had been twisted by the tornado, had recovered and almost healed. It was snapped off like a straw at this weak spot. The arbor vitae (*Thuja occidentalis*) is a tree whose soft wood has little resisting power. The tops of these trees were broken very badly, and such as were not broken were bent so far from the vertical position that they did not go back to the same. The soft maples (*Acer dasycarpum*) were most affected. Large and small limbs of this useful shade tree were broken off, and there were few trees which escaped entirely. The honey locust (*Robinia pseudacacia*) lost many branches, likewise the oaks, ash, peach and apple trees. Some trees escaped entirely, notably the cypress (*Taxodium distichum*), which likewise successfully resisted the tornado; furthermore, the gingko (*Gingko biloba*), whose long, sweeping branches bent under the load, but did not break. The pines suffered very severely.

The ice remained on the shrubs and trees for several days, and not until March 5th was it entirely gone. The branches gradually resumed their original position, while the trunks did so more slowly. The lower figures on Pl. X, XI, are from photographs taken just one week after the storm, March 6th. The camera was placed at the same points as it had been in taking the photographs immediately after the storm. The branches of the hornbeam returned to their former position, with the exception of one branch which was broken by the load. The maples on Flora avenue show some residual effect. The ice remained on the trees for so long a period that the wood on the convex side became stretched, and when the top returned to the vertical position, the stretched side remained somewhat convex. How long the bent position will last, cannot be guessed at this time. These trees are still bent at this writing (April 2d). The trees in the central row are birches (at the left of the figure). They have straightened completely. The arbor vitae and related coniferous trees show the residual effect of the ice more than the trees of the hardwood type.

The weight of ice which the trees were called upon to bear was a very great one, greater than any that has been known in this region for many years. The ice can hardly be considered an ecological factor in the life history of a tree in this climate, for it is a factor which exerts an influence on the branches at such very great intervals of time that any reaction or adaptation to the same cannot possibly take place.

One can ask, therefore, how it happens that so many of the branches were able to withstand successfully a weight so great as the one described. The only other force which might act in depressing branches is snow. But its weight is exceedingly small when compared with ice, and its influence on the branches of deciduous-leaved trees is of the smallest. It is therefore necessary to account for the strength of the branches in another way.

The wind is a factor, constantly at work, and its influence in shaping the form and strength of the plant body has been duly noted.* It exerts a pressure on the branches which at times is very considerable. In the course of time the branches of trees have acquired sufficient strength to withstand this pressure, and only when the same exceeds a certain limit, as in tornadoes and hurricanes, do the branches break. The pressure exerted by the ice is much like that exerted by the wind, in many ways. It is a steady pressure, and in that respect, perhaps, more effective than the pressure exerted only now and then by the gusts of wind. But the action is one affecting the strength of the branch. It therefore becomes less astonishing that so many of the trees successfully bore the great weights of ice placed upon them, when one reflects that these same trees resist similar strains which act at frequent intervals. They have adapted themselves to these, and were consequently able to withstand the unwonted ice pressure.

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* Schimper, A. F. W. Pflanzengeographie. 84. 1898.— Metzger. Der Wind als massgebender Faktor für das Wachstum der Bäume. Mündener forstliche Hefte. **3.** 1893; also **5** and **6.** 1894.

EXPLANATION OF ILLUSTRATIONS.

PLATES X–XI.

Pl. X. — *Upper figure.* A group of horn beam trees (*Carpinus betulus*) in the arboretum of the Missouri Botanical Garden on the morning of Feb. 28, 1900.—*Lower figure.* The same group of trees on the morning of March 6, 1900. Note that one branch has been broken.

Pl. XI. — *Upper figure.* View looking east on Flora avenue, St. Louis, on the morning of Feb. 28th, 1900. The tree in the foreground is a soft maple (*Acer dasycarpum*), likewise the row of trees of which it is one. The trees at the left are birches (*Betula alba*). — *Lower figure.* The same street (from the same spot) just a week later, March 6, 1900. Note that the maples have not quite returned to their original position, while the birches have.

Issued April 12, 1900.

SLEET EFFECTS.
(Carpinus betulus.)

SLEET EFFECTS.
(Acer dasycarpum.)

ON CERTAIN PROPERTIES OF LIGHT-STRUCK PHOTOGRAPHIC PLATES.*

FRANCIS E. NIPHER.

The results to be given in this paper were obtained with a Töpler-Holtz machine having one 24-inch plate, and with no condenser attached to its terminals. The spark-length mentioned in the paper is the distance between the discharge knobs of the machine.

A parallel circuit consisting of ball-tipped brass rods about six feet in length led to the insulated stool upon which the photographic plate is placed for electrical exposure. A brass plate a foot square was placed on the top of an insulated stool, and formed one plate of a condenser. Upon this a much larger glass plate is placed, upon which rests the photographic plate. All of the results were obtained with the Cramer "lightning" plate. Some metallic object like a medal is placed upon the sensitive film, and forms the other plate of the condenser. A rod about a foot in length, having knobs, stands vertically over the medal. The knobs of the secondary or parallel circuit are separated from the plates of the condenser and from the machine terminals, by small spark gaps which may be varied. Such changes appear to materially affect the behavior of the machine and the details of the picture produced. The rods are all sleeved by glass tubing, and are then held by laboratory clamp stands. This arrangement for electrographing is well known although the photographic plate has heretofore been protected from the light.

The method which has been found most convenient for manipulation is to first expose the plates to the light of an ordinary room for from one to nine days. A longer interval

* Presented in abstract to The Academy of Science of St. Louis, March 19, 1900.

has not been tried, but some of the best results were obtained from the last of a box of plates which were all exposed at the same time, and which were not all used until nine days had elapsed. This method of treatment is advantageous because it is difficult to prevent light from the discharge from striking the plate during the electrical exposure, and a great over-exposure renders the plate more manageable in the subsequent treatment. It darkens much more slowly in the developing bath than when slightly light-struck.

The plate is put in position with the medal resting upon it. The capacity described gives a rather rapid sequence of small sparks, which may be made 15 cm. in length. At each discharge between the knobs of the machine, a discharge occurs on the film around and under the medal. This exposure may be from four to ten minutes. A much longer exposure reverses the picture and gives a positive. The exposure should be in a darkened room, and the light from the spark should be kept from the plate by a screen. Light falling on the plate while the electrical action is taking place, counteracts the electrical action in a very remarkable way. This may be shown by partly closing the blinds of a window ten or fifteen feet away, forming thus a vertical slit a foot in width. The other blinds are to be wholly closed. A book set up so as to shade half of the plate yields results such as are shown in Fig. 1. This print is of course a positive from the original negative.

It is therefore evident that the time of exposure depends somewhat on the diffuse illumination in the room. A very dark room is not necessary.

It is also found that if the plate be exposed to light for a day or more after the electrical exposure, a similar counteracting effect is produced. In this way the picture may even be reversed and develop as a positive.

In developing the picture a cool and rather weak hydrochinone developer leaves nothing to be desired. The room should not be too dark during this operation. The best conditions are to be found in an ordinary dark room, lighted by a single incandescent lamp. The light should be five or six feet away, and any tendency to fog is remedied by taking the plate nearer to the lamp. If already fogged, a plate may thus be cleared up in a very remarkable way. If the plate is too near the light during the whole time, there is a loss of detail. By allowing the developing to begin four or five feet from the lamp, moving it up as necessity arises to within two or three inches, and with a cool and weak developer, the picture may be developed for an hour if desired. During this time the details are coming out with continually increasing sharpness.

When the spark length is less than twelve or thirteen millimeters, no disruptive and luminous sparks are seen on the plate. There is a violet corona around the medal. The pictures given by the positive pole show radial discharges, bounded by a dark band, like a halo. For short spark lengths of 5 or 6 mm., the halo is close around the medal, and it increases in radius as the spark length increases. With a spark length of about sixteen millimeters, a dark halo appears distinctly on the plate before developing. This has been seen only a few times. Thus far it has not been found possible to save it. It washes out in the developer. It begins to fade and an inner one, apparently midway between it and the medal, begins to appear. The outer halo has disappeared, before the inner one has fully developed. When the developing is arrested at an earlier stage, the outer ring is lost in the fixing bath.

The shape of the dark halo conforms to the general shape of the body. In some cases, where disruptive effects of exceptionally strong character have passed, their tracks are shown on the negative. These tracks are in all cases distinctly broader and darker where they cross the dark halo, than elsewhere.

Figs. 2, 3 and 4 show some of the peculiarities mentioned. In Fig. 2 the spark is delivered to the large weight, but the smaller one is so near that it has very nearly the same potential as the larger. It is joined to the larger by a spark, which practically unites the two bodies at each discharge.

In Fig. 3 the smaller weight has a much lower potential than that of the larger. It corresponds nearly to that of the halo encircling the larger weight. In Fig. 4 the distance between the weights is still greater, and the smaller weight is at a lower potential than that of the halo around the larger weight. With a spark length between thirteen and twenty millimeters, disruptive sparks begin to appear around the medal, and the discharge picture changes its character entirely. Not only is it greatly different from those previously described, but as in all other cases it does not correspond to the appearance which it presents to the eye. See Fig. 5. The visible spark discharges show a curious tendency to turn at right angles, and seem to be unsteady and flickering in their outer extremities. As the spark length increases the disruptive discharges become several inches in length, and the general appearance of the field as shown in the negative, is shown in Fig. 6. In this figure the spark is delivered to the larger disk. In most of these cases the development has been arrested before the tracks of the visible sparks appeared on the negative. No discharge like those shown on the negative can be detected by the eye. If the knobs of the machine are separated so widely that no sparks can pass, the brush discharge gives very feeble results if exposure and developing are otherwise done in the same way as before. This applies both to the image of the object and to the field around it. The oscillating spark discharge appears to be the important element rather than luminous or electrolytic action. Certainly the luminous effect is distinctly prejudicial.

The negative discharge shows much less of interesting detail. With short sparks, there is a smooth corona, looking like a brush shading in India ink. With longer sparks some radial line-work suggesting lines of force appears. See Fig. 7. The general appearance is much the same for short as for long spark lengths. When strongly illuminated during the electrical action, both positive and negative discharges give weak coronal effects in the negative, and the color is that of a sepia stain, or an untoned silver print. Most of the interesting features which the negatives show must be passed over without mention. They pertain largely to effects due to variation of capacity and spark gaps both in the main and the parallel circuits. The perfecting of the methods and the study of these features occupied a period of several months, and a large part of this work was done during 1896.

While recently observing a plate exposed to the negative discharge, half of which was shaded, a bright ball of light looking like a globule of molten metal rolled slowly out into the shadow from the brass weight. Its size appeared to be that of a pin's head. It moved somewhat irregularly and left a black narrow track in its wake. The discharges which had previously been in all directions around the medal were now all on the side occupied by the ball. They were less frequent, and the sparks were apparently within an angle of 30° or 40°. They, however, did not pass along the track of the ball, but rather appeared to avoid it. Another ball appeared from the same point on the coin and the first disappeared. The second ball soon diverged from the track of the first, and slowly made its way outwards. Several others followed. The plate was finally developed, and these tracks appeared as a branching system of black lines, wholly unlike anything before observed. The experiment was repeated, and a similar result followed. It was then thought that the shadow in which they made their appearance might be concerned in the phenomenon. In the next plate, however, the balls appeared in the part of the plate which was strongly illuminated. The development of this plate was pushed to the extreme. and the branching track began to appear blurred. On examination with a pocket lens, it was found that the tracks of the ordinary spark discharges could be detected where they crossed the tracks of the ball discharges. They were here intensified. Under the glass the spark discharges appeared indistinct and hazy, while the tracks of the balls were still sharp. See Fig. 1. When rephotographed and enlarged 100 diameters, the tracks of the balls on the original negative were found to be about 0.002 cm. in width.

Some changes were then made in the apparatus in order to provide more suitable conditions, and it was then found impossible to secure the result again after two days of persistent work. The old arrangement was then resorted to with like results. It was observed that the ball discharges came from the same point on the brass weight. A short radial pencil line was drawn on the plate at this point with no result. There seemed to be no irregularity at the point of discharge that could account for the peculiar discharge. The brass wheel of a clock was selected, and all but one of its pointed cogs were removed, with no better result. A return to the weight gave a successful result, but continued repetition resulted again in failure. A radial line was again drawn with a different pencil from that formerly used, and with a successful result, but this was again followed by a long list of failures. It was finally found that the mark of a moistened pencil would always yield the desired result.

This threw discredit upon the idea which had begun to prevail, that a definite frequency of oscillation was involved, and which only a fortunate combination of adjustments could secure. After a month of experimenting in this way the conditions favorable to the immediate production of the phenomenon were found.

The secondary circuit was discarded, and the metal disk from which the discharge is to come was put in contact with the negative knob of the machine. The disk was armed with a radially placed needle point, which touched the sensitive film. No condenser was used in the machine, and the knobs were separated so that no visible discharge could occur between them. A needle point is also presented to the point on the surface of the film. A very effective device consists of two needles or pins with their eye or head ends lashed together, and attached with sealing wax to the end of a glass tube serving as a handle. The needles form the arms of a T of which the glass tube is the trunk. One point is held near the point from which the balls are to issue upon the film. The other point discharges upon the air. This device has earned the name "teaser." It seldom fails to bring the ball discharge at once. The mark of a moistened pencil upon the film at the discharge point is sometimes needed. The teaser may also be used to lead the balls into abnormal paths upon the plate. When this device was hit upon, it was at once used to determine whether ball discharges could be drawn from the positive pole. The discharge point was placed at the positive pole, with the teaser held in front of it. The balls appeared, but they issued from the teaser and passed to the positive pole. Several negatives were obtained in which short discharge tracks exactly resembling those of the ball discharge, were found originating in irregularities of the film. This suggested the experiment, the details of which are shown in the adjoining cut. A disk, *b*, *c*, was armed with two needle points, one of which was directed towards the point *a*, from which the ball discharges issue. The other was directed in an opposite direction. The positions of the knobs of the machine are shown in the cut. A very luminous ball discharge passed very slowly from *a* to *b*, requiring about a minute to traverse one inch. At *b* the luminosity disappeared, but it appeared at once at *c* and drifted around towards the + knob. It reached the edge of the plate at *d*, and remained

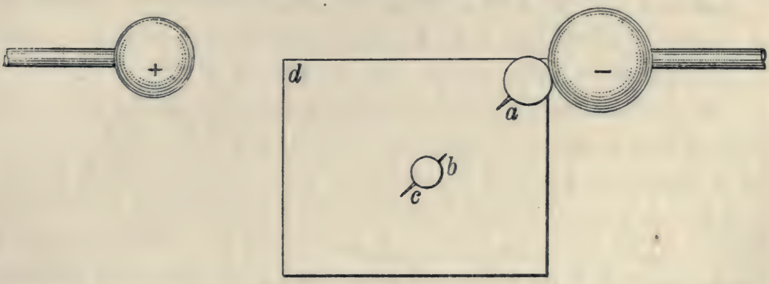


DIAGRAM SHOWING THE ARRANGEMENT OF DISCHARGE IN PL. XV., FIG. 8.

there for several minutes. A little rivulet of violet discharge passed along the whole line of the track and was especially strong near *a*. After developing it was found, what has been seen in several other plates, that the film was attacked along this part of the track, as is shown by dendritic formations extending outward from the main track but which do not show in the half-tone reproduction. When the machine was stopped and the flow along this line ceased, it was found on starting the machine that this track had ceased to act as a conductor. No glow appeared at *d*. Another ball discharge appeared. It was drawn out and to one side of the old track by means of the teaser, and then was allowed to traverse its own path. It found its way by a new path, to *b* and *c*, and finally to the edge of the plate. There it also persisted, but the machine was soon stopped, and the glow ceased. This was repeated many times. The result is shown in Fig. 8.

It was found in this experiment, as in all others, that the track of a ball discharge is a good conductor, so long as the ball discharge is in existence at the end of the path. It affects the operation of the machine in a very remarkable way, as has been explained, when strong disruptive discharges are taking place. If a ball discharge intersects the track of another ball discharge, it will sometimes move along this track with great speed, but sometimes it disappears and at the same time it reappears on the same track further away from the cathode. But as a rule these balls cross and recross old tracks while running closely parallel to them, without being in the least affected by their presence.

It is not probable that these discharges are really spherical in form. Sometimes they do not even appear spherical. The phenomenon is apparently the result of a breaking down under electric stress of the medium composing the sensitive part of the film. The chemical action results in the formation of a track along which a discharge passes to feed and maintain these luminous nuclei. This discharge along the track between the cathode and ball is usually invisible, even in a dark room, but its existence can always be shown by passing the point of the teaser along the track. By separating the knob of the machine from the disk bearing the discharge point this silent brush discharge also becomes apparent.

If a drop of water be put on a not too clean plate of glass, and at the end of the discharge point *a* of diagram, the water is drawn out into long narrow tracks. They originate at points of maximum curvature, where a luminous point discharge appears. This action results in the formation of a conducting track which feeds the point discharge. But a similar action will take place at the positive knob of the machine. Only part of the conditions existing on the photographic plate are found here. The medium is a conductor, which is distorted by the acting forces. There is no chemical breaking down of the medium, resulting in the formation of a conducting channel.

After a plate containing a ball discharge has been fixed and dried, if it be replaced at either discharge knob of the machine, luminous ball discharges form along the tracks, but the conducting material forming the track is quickly torn out and dispersed. In a few cases these points or ball discharges have been seen to move quickly along the old tracks, but as a rule they do not appear to be capable of motion. Such motions as have been seen were away from the cathode knob, and they consisted in most cases rather in a disappearance of a glowing ball-like mass at one point, and its reappearance at an adjacent point. Only one or two negatives gave results of any significance. In most of them the film as a whole had become either too good or too poor a conductor.

It is apparent that the gradual formation of a channel of somewhat lower resistance, is a material feature in the ball discharge. It is probable that the breaking down of insulating material by stresses due to high potentials will yield valuable results. Whether these ball discharges on the photographic plates are the same as those reported in connection with lightning, it is perhaps too early to decide. They are certainly similar. It is very probable that optical illusions are to be credited with some of the descriptions given of these phenomena. The remarkable photographs taken by Sidney Webb and recently published,* show that during lightning discharges, tracks stream out from arc lights. The line wire is a conducting channel. The arc itself is a point of weakness in the gaseous medium, by reason of its high temperature. At low temperatures, nitric and nitrous fumes when mixed with air, increase its resistance to the passage of sparks between discharge knobs; but at high temperatures the result is likely to be different. Certain it is that these photographs taken by Mr. Webb, show that just such discharges are formed in the air as are known to exist along the track of a ball discharge on the photographic plate.

In many cases where spark intervals have been specially adjusted, and a continuous violet brush discharge was seen passing along the track leading to a ball, persistent appearances resembling what has been described as bead lightning have been observed. These beads were really incipient ball discharges that were about to branch out from the main track. Such branches are seen in almost every negative secured.

* Nature, Feb. 8, 1900.

In many cases such attempts to form branch tracks prove abortive, but all of the tracks which are maintained for a sufficient time show most elaborate branches, of the most beautiful form. This is especially true when the photographic plate is not too near the machine, and when the teaser is only used to start a ball, which is then allowed to wander over the plate. The most interesting ball discharge yet obtained was found on a plate inclosed in a paste-board box in which photographic plates are packed. The discharge was disruptive in character. The negative terminal was a small knob in contact with the coin, from which a wire passed through the center of the cover, and was held in place by sealing-wax. The ball discharges wandered over the entire plate. They even branched off towards the coin and two such branches ran under the coin itself. The X-ray was playing upon the plate during the exposure, but this was apparently not an essential feature. The walls of the box undoubtedly did have some influence.

The essential differences between the three kinds of discharge described are well shown in Fig. 1, which contains them all. Ordinary visible disruptive sparks are shown most sharply in that part acted upon by the light during the discharge. They are not sharply defined, and are curiously bent near their outer ends. When first appearing on this negative, they were dark. As the development was pushed, they reversed. The dark corona on the negative immediately around the brass weight was produced by radiations along the lines of force. They were straight lines or nearly so, and the discharges which produce them are invisible. Within this coronal discharge in the shaded part of the plate will be found the track of a ball discharge, which on an ordinary silver print comes out very sharply, under a strong lens, but the reproduction will not bear very much of magnifying.

Fig. 9 shows a ball lightning discharge from a plate which was pushed somewhat in the developing bath. It would have been very nearly as good if it had been fixed without developing at all. It is, however, somewhat better to develop, if the arrangement has been such that disruptive sparks have not passed over the plate.

Fig. 10 is a reproduction of a portion of a negative showing ball tracks magnified about one hundred diameters. While these tracks were being traced, disruptive sparks were passing continually over the plate, and the tracks appeared somewhat obscured when viewed with the unaided eye. A pocket lens showed well defined tracks, and in the enlarged photograph the blurred effect has entirely disappeared.

This picture has been reversed twice, and shows the tracks in black as they appear on the original negative.

The fact that greatly over-exposed plates may be developed in the light, was suggested by the fact that in exposure to light during the taking of an electrograph, the electrical action was annulled. Finally when a plate which at first promised well began to fog in the dark room, the light of an incandescent lamp was turned on, and the plate at once cleared in a most remarkable way.

This again suggested the idea of developing X-ray pictures in the light. This has also been done with very satisfactory results. Light-struck plates were used for this purpose, which had been exposed for a day to the diffuse light of the laboratory. Singularly enough these pictures were negatives when they were inclosed in black paper during the X-ray treatment, and they were positives if they were exposed to the light while the X-ray was acting.

The advantage of being able to study an X-ray picture during the operation of the developing is sometimes very great. The operation may then be pushed until the desired features have been brought out, and it may be arrested before they are obscured by over-developing.

When the X-ray is thrown upon a plate in a camera while an ordinary picture is being taken, all exposed parts of the plate are affected alike. The action of light and of the X-ray are added. If a picture be taken of a diagram in black on white cardboard, the action of the X-ray will be shown equally on the dark and the light parts of the image. This is made evident by shielding half of the plate from the X-ray by a screen of metal or of lead glass. There is a marked difference between this result and that found for the superposition of light and electrical action, as is shown in

Fig. 1. In order that the X-ray picture of the metal fittings of the camera, and the light picture of the object in front of the lens may be superposed on the fixed plate, the diaphragm of the camera must be so set that the two pictures will develop in the same time with the same developing bath.

The results already described suggested that in ordinary photography the exposure might be so modified that the picture might be developed in the light.

In the first attempts that were made the object was a street scene. The exposures were from one to three and a fourth hours. The pictures developed in the light with perfect clearness. They are of course positives. They appear somewhat unpromising at first, while in the developing bath, and one is tempted to abandon them as failures, as indeed some of them may be, until experience is gained. The pictures obtained by these long exposures show some very interesting features. They show no trace of moving objects on the streets. In some cases hundreds of people passed. In one case ten street cars were blocked for twelve minutes, in the foreground, and cars were passing at the rate of 70 to the hour. Wagons were driven to the curb to deliver goods to houses, and people were standing on the street corners waiting for cars. In an exposure of an hour no trace of these objects could be seen on the plate when developed. The street appeared absolutely deserted. The car tracks show with distinctness. In one exposure of three hours and forty-five minutes a team and wagon stood in one position for twenty-eight minutes, and no trace of them appeared. If the exposure of the same plate is only for one second, these moving objects are all shown. Another feature of these long exposures is the entire absence of shadows. It is somewhat difficult to account for this, as it hardly seems possible that their motion is sufficiently rapid to produce this result. The sky appears absolutely uniform. Clouds which were in marked contrast in one case yield no trace upon the picture. An attempt was then made to shorten the time of exposure and still permit development in the light. This was done by subjecting the plate, while in the plate holder, to the X-ray.

The plate holder was held for ten minutes, six inches from a Crookes tube operated by a large induction coil in oil. A perfect picture of the hand could be obtained in six to eight seconds. The same plate was then exposed for two hours to a Crookes tube operated by a large eight-plate influence machine. The plate holder was then put into the camera and exposed to a street scene for ten minutes and was then developed in the light. The result is shown in Fig. 11. For reproduction of form and shadow, this plate could hardly be excelled by a transparency made in the ordinary way. Like the others, it shows no trace of moving objects on the street.

It has been long known that a slight over-exposure of a plate in the camera sometimes gives a positive picture when developed in the dark room. The experience thus far described made it seem probable that such pictures might also be developed in the light. This was found to be the case. If the proper exposure is one and a half to two seconds, an exposure of a minute is sufficient. Some that have been made have not been very satisfactory. But one has been obtained which is even superior to the plate reproduced in Fig. 11. It is shown in Fig. 12. For richness of finish and for perfect modulation of light and shadow, this original plate leaves nothing to be desired. During most of the time while being developed, it was held one foot from a sixteen-candle lamp. During some of the time it was held nearer, and during some of the time it was five or six feet from the lamp.

Figs. 11 and 12 are of course reproductions of the original positives. In these exposures the Cramer isochromatic plate was used.

In some of these shorter exposures where people or wagons halted on the street, they are shown on the fixed plate. Where they were motionless during the whole exposure they are of course shown with perfect clearness.

Experiment shows that a conspicuous object two feet in breadth and fifty feet from the camera if moved transversely at the rate of twenty feet per minute, during an exposure of one minute, will show on the plate as a distinct trail. With a longer exposure it is eliminated. The unit of exposure may be roughly considered as one candle-meter-second. With a fixed illumination, the exposure may be varied, by varying the time of exposure. It appears that for any exposure, there is some definite degree of illumination in the dark room, which will yield what might be called a zero plate. No picture will appear on it if lights and shadows are each uniform on the object, as in case of a diagram in black on white cardboard. This picture will become a negative in a darker, and a positive in a lighter developing room. With an exposure of half a second a plate which will develop as a perfect negative in a proper dark room, will develop as a zero plate if the room is dimly lighted. In the parlance of the photographer, it will fog. In a still brighter light it will develop as a positive. In this action there must be a time co-ordination in the action of the developer and the light of the dark room. With a given strength of developer it appears from results thus far obtained, that a maximum degree of excellence will be secured with a definite degree of illumination in the dark room. The results thus far obtained with half-second exposures, are by no means satisfactory, considered as products of the photographer's art, but the pictures of street scenes are distinctly positives. If results comparable with those for longer exposures are attainable, it involves a delicate adjustment of the illumination of the dark room and strength of developer which has not so far been secured.

With an incandescent lamp burning in the dark room, it is easy in half-second exposures to obtain a rather poor negative, by holding the bath in the shadow of an object eight or ten feet from the lamp. By holding the plate in the light, and going somewhat nearer, the same plate with the same exposure, will yield a picture which is distinctly a positive.

With a very much over-exposed plate, it is difficult to get a room dark enough to yield a negative. With a very short exposure, it is equally difficult to get positives, and only by a very great illumination of the plate while in the developer. The condition of zero plate when only the time of exposure and the illumination of the developing room are variable, certainly cannot be very different from an inverse proportion. The experiments thus far made show also that with a long exposure, the best results can be obtained by developing the plate in the light, as a positive, while for very short exposures the best results are attainable by developing as a negative.

These conclusions may be modified by a variation of the strength of the developer. The limits within which the variables may change and yield results of commercial value have not been determined with precision for positive pictures. What has been said of pictures taken in the camera, may also be said of X-ray pictures on plates not previously light-struck. If two plates are exposed in the same way to the X-ray, and one be developed in the dark and the other in the light, the former develops as a negative and the latter as a positive. Either may be converted into a zero plate by a change in the illumination of the plate while in the bath, as has been previously explained. The more careful study of these subjects is still in progress. There is ground for believing that the treatment of a plate by a slab of plaster of Paris moistened with peroxide of hydrogen, according to the method used by Russell * may be of value in developing X-ray pictures in the light. Work in this direction has not yet progressed sufficiently to warrant any final conclusions.

The superposition of X-ray pictures on electrographs does not as yet reveal any effect of either agent upon the action of the other. This has been done with fresh plates and with those which had been previously light-struck. In these experiments half of the plate was shielded from the X-ray by a heavy plate of lead glass. The pictures due to the two sources were superposed, and the two effects were added where simultaneously acting. This is also in marked contrast to the action of light on the electrograph, as is shown in Fig. 1.

The superposition of X-rays upon a plate in the developing bath while in a dark room promises interesting results, but so far this has not been done from lack of time.

* Science, March 30, 1900, p. 491.

EXPLANATION OF ILLUSTRATIONS.

Plates XII–XVII.

Plate XII. — 1, Electrograph with light from one window falling on the left half of the plate. The right half is in shadow. Negative pole. — 2, Electrograph with positive pole with plate exposed in a moderately dark room. Discharge upon the large weight.

Plate XIII. — 3, Same with small weight at a greater distance. — 4, Same with the small weight still further removed.

Plate XIV. — 5, Same with greater spark length. — 6, Same with still greater spark length.

Plate XV. — 7, Electrograph with negative pole, long spark length. — 8, Ball lightning discharges. — See diagram in text. Fig. 8 has been reversed in the reproduction.

Plate XVI. — 9, The same as Fig. 8. — 10, The same enlarged 75 diameters and shown twice reversed.

Plate XVII. — 11, Ordinary photograph — exposure 10 min. on a plate previously fogged for two hours in X-rays, and developed as a positive in the light. — 12, An ordinary photograph — exposure one minute. Developed in the light. The original is also a positive.

Issued May 16, 1900.

FIG. 1.

FIG. 2.

FIG. 3.

FIG. 4.

FIG. 5.

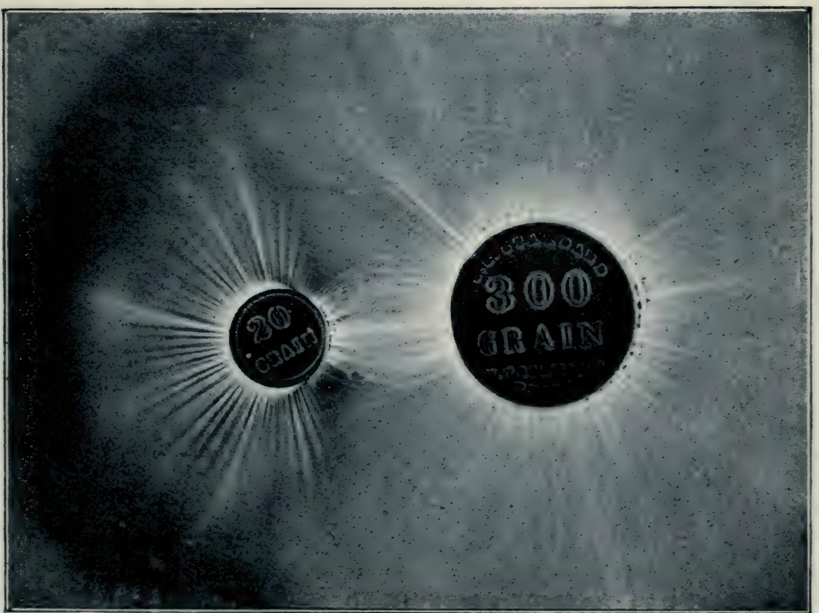


FIG. 6.

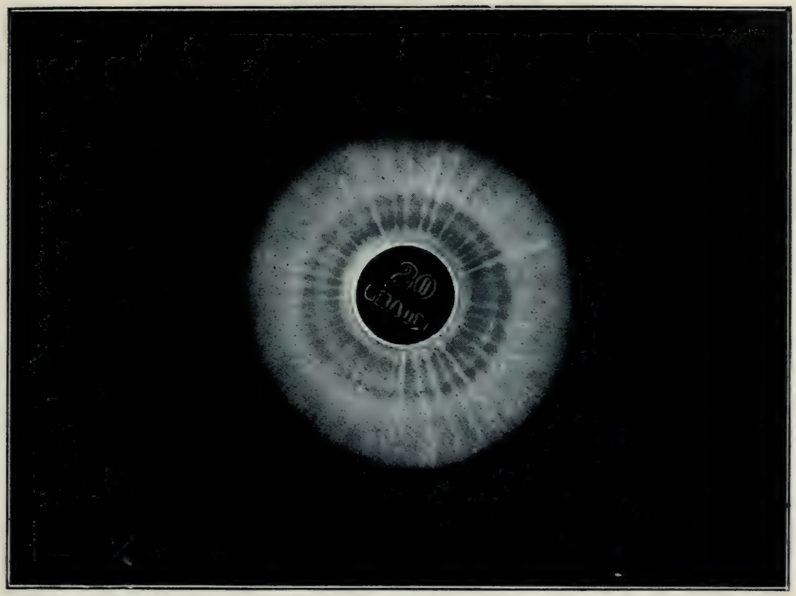


FIG. 7.

FIG. 8.

FIG. 9.

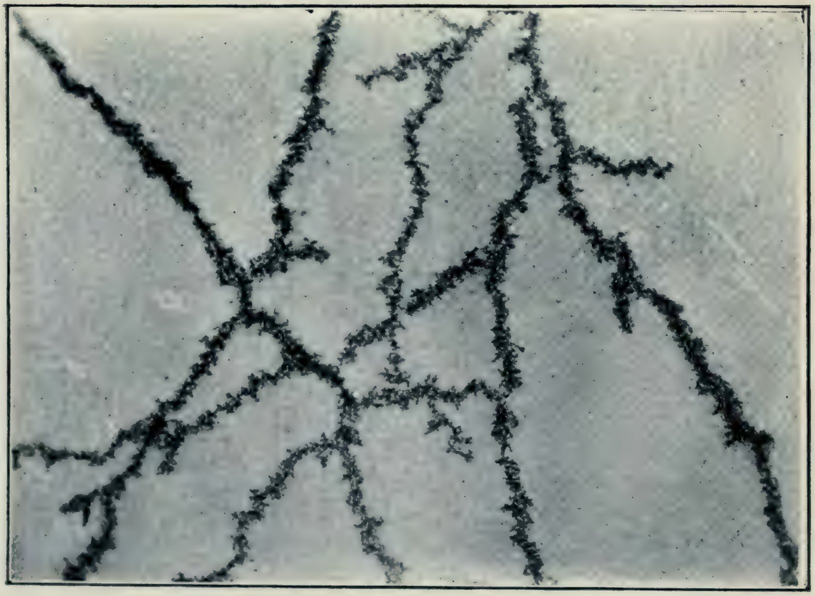


FIG. 10.

FIG. 11.

FIG. 12.

THE DEVELOPMENT OF AGARICOCRINUS.*

MARY KLEM.

In recent works on the Crinoideae of North America, we find the writers relying upon the variations in the proportions of the interbrachial plates, and upon the form and size of the costals and distichals as the best distinctive characters for specific separation. The number and distribution of the arms, the form of the anal area, and the condition of the oral plates, are also important features.

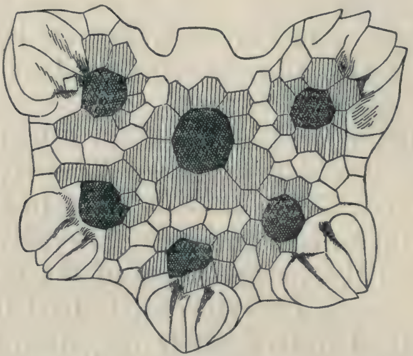
I have examined a large and excellent collection of Agaricocrini, numbering over one hundred well preserved specimens, gathered at Moore's Mill on the Fox River, in Clark County, Missouri, from the Keokuk formation. The diversity of their general form and the various stages of the development of the plates, comprising the calyx, would tend to support the above statements; but, on closer investigation, I became fully convinced that the specimens before me belong to but one species. The fact that these fossils were found within the small radius of one-eighth of a mile strengthens the stand I take on this question. I consider the prevailing differences in the plates the result of abnormal development, otherwise I would have one hundred species of the same genus from one locality, which is an utter impossibility.

On the ventral side of any one of these specimens, there are invariably six prominent plates, each of which is surrounded by a more or less perfect ring of smaller pieces. In all the specimens that have come under my observation, and in the drawings I have examined, I have found these essential points. This fact led me to the following conclusions concerning the development of this genus.

According to my conception of their development, the first plates to be formed were the orals, six in number. These

* Presented by title to The Academy of Science of St. Louis, May 7, 1900. Presented to the Faculty of Washington University as a thesis for the Degree of Bachelor of Arts, June, 1900.

plates are always large and prominent in this genus; the posterior one being usually larger than the other five and central. They divide the ventral side into five spaces occupied by smaller plates. Four of these areas are about the same size, while the one on the anal side is much larger. (See figure.) The condition of the orals varies considerably; sometimes they are tuberculose as in *A. excavatus*, nodose as in *A. bullatus*, spinous as in *A. stellatus*, or conical as in *A. Coreyi*.



DEVELOPMENT OF AGARICOCRINUS AMERICANUS.*

The next step in the development was the formation of a series of smaller pieces around each oral. This ring can be traced more or less distinctly in every instance, but in no two cases is it composed of the same number of pieces, or of pieces of the same size. The variations in the size, shape and number of these plates, in all probability, depended upon the quality and the quantity of food, the amount of light and the nature of the surroundings. If the animal was healthy, well-fed, and the environments were favorable for rapid growth, it seems plausible to suppose that it developed large plates, but few of them; if the nutrition was poor and the conditions were adverse, then a large number of much smaller plates formed. Very often we find a number of small plates inserted between

* The six plates shaded heavily were the first plates to be deposited. The series of smaller plates around each, which are shaded lightly, were the second step in the development. The intervening pieces, which are not shaded, were formed at a later period as the necessary material could be produced.

the orals and some of the plates composing the ring, as shown in Figs. 5, 18, 22 and 25. These may have been formed while the animal was sick or in a poor locality. Upon a return to more favorable conditions, the ring of larger plates was deposited. The isolation of the orals by these supplementary pieces cannot very well be regarded as of specific importance, as there is no regularity in their occurrence.

Because of the great variety in the shape, size, and number of the pieces, I think the intervening spaces were filled out as the necessary material could be produced. The sole purpose of these plates seems to be to fill out space, no one knowing any functions which they might have had. Since their only object is to connect the different parts, it is very reasonable to suppose that they made their appearance at a later period than the orals and the basals, which appeared simultaneously. Here, again, it is impossible to find any two specimens in which the spaces have been filled out in the same manner. An examination of the drawings accompanying this paper will show every possible combination, resulting from the factors with which the animal had to contend. The number of drawings could have been multiplied many times, but I think those submitted are sufficient to show the chief features in the development, and the departure in each case from the regular pentamerous arrangement.

This process of development necessarily affected the general shape of the calyx, making it hemispherical as in *A. Americanus*, pyramidal as in *A. excavatus*, conical as in *A. conicus*, or inflated as in *A. inflatus*. In many cases the symmetry of the body was destroyed by the addition or the removal of arms or plates. The size of the calyx is of little value for classification, as it depends entirely upon the size and number of the component plates.

Examining the dorsal cup, I found a great similarity in the general arrangement of the plates, but differences in the number and in the size of the plates were as prevalent as on the ventral side. The many variations in the structure have been mistaken for specific differences, giving rise to useless synonyms.

The first radials vary much in size, being the largest plates of the dorsal cup in some, and quite small in others. In many they are irregular in size, the posterior ones being generally longer than the others. Often the sides are spreading, the lower ends thickened to form a circular ridge around the depression for the column. The second and third radials are among the most variable plates in the disk. The second radials are usually quadrangular with convex sides, but frequently one or both upper angles are truncated by the second interbrachials. In some three are hexangular, and the two posterior ones pentangular; or all are quadrangular, except the one on the anal side which has one of the upper angles truncated, making a fifth angle. There is considerable range in size; in some specimens they are larger than the first radials; in some they are the largest plates in the disk, and in others they are very short, more than twice as wide as long. The third radials are regularly five-sided, but pieces with six, seven and eight sides are of common occurrence. Sometimes they are irregular in outline, or all pentangular, except the posterior ones which are hexangular. In some they are triangular and so small that the first piece of the brachials rests in part on the second radial as well as on the third. As the first and second radials, so these may be the largest plates in the disk. Often they are tumid and project beyond the surface of the first and second radials.

The distichals and brachials are quite variable in form and size, as well as in number among the rays. In many the first distichal of the three anterior rays is followed by a cuneate second plate, while the posterior rays have one distichal, followed by two palmars, or only one distichal with one palmar. The second distichal may be quite small and cuneate, the outer ends being occupied by arm plates which meet it from opposite sides. Usually there are two series of alternating brachial pieces which form the base of two arms. Additional arms are produced by the intercalation of brachial pieces between the others.

The first anal is usually longer than the radials and followed by a second anal and an interbrachial on each side, which extend to the arm bases and beyond the second anal. This is not constant, however, the anal being smaller than the radials and of various shapes in many specimens. The next row generally consists of two short plates, succeeded by numerous small, irregular pieces, forming the anal area. This row frequently comprises three, four or five plates, which may be as wide as long, as large as the radials, or almost twice as large.

Upon examination the interbrachials will be found to be as variable in size as the radials and distichals. In some the first plate rises almost to a level with the arm bases, in others it barely reaches the middle of the second radial. As a result the second brachial plates come much lower, which makes them more prominent in the structure. They are brought in contact with the second radials, cutting off their upper lateral angles, making these plates hexagonal instead of regularly quadrangular. The two of the second row are, as a rule, twice as long as the first and very narrow, while the plates of the third range are quite variable in form and size and often partly interambulacral. The interambulacral areas are filled out with from five to nine small convex pieces. The variations in the proportions of the interbrachial plates cannot be of specific importance because, if the first interbrachials are small, the second ones are necessarily forced lower down in the cup and become more prominent, while, if the first interbrachials are long, there is no need for the second ones to be large and they remain narrow and do not truncate the second radials on the upper lateral edges as in the former case.

In their normal state the Agaricocrini of the Chouteau and Burlington Groups have ten arms and those of the Keokuk Group twelve arms, three upon each of the posterior rays and two upon each of the others. The number of arms is not constant however; additional arms frequently appearing as the result of abnormal development, or one or more arms remaining undeveloped. When a series of specimens, such as I have figured, is carefully examined, the most striking feature is seen to be the irregularity in the number and size of the arms. The normal forms in the Keokuk Group have the following arm formula*: 3+3+2+2+2. Of the twenty-six specimens figured, ten have twelve arms, the formula in Figs. 4, 7, 14, 16, 20, 21 and 24 being 3+3+2+2+2; in Fig. 25, $3+3+1_1+2+2$; in Fig. 22, $1_1 1+3+1_1+1_1+2$; and in Fig. 2, 3+4+2+1+2. One, No. 12, has thirteen arms of this formula: 3+3+2+3+2; No. 10 has seventeen arms arranged thus: 4+4+3+3+3. Six have eleven arms, the formula in Figs. 13, 15, 17 and 26 being 2+3+2+2+2; in Fig. 6, $2+3+2+1_1+2$; and in Fig. 8, 3+2+2+2+2. Of the rest six have ten arms and two nine arms. In Figs. 5, 9, 11 and 18 the formula is 2+2+2+2+2; in Fig. 3, $2+1_1+1_1+1_1+2$; in Fig. 1, 3+2+2+2+1. For Fig. 19 the formula is 3+2+2+1+1, and for Fig. 23 it is 2+3+2+2.

A lack of proper regard for this occurrence has led many writers to create new species, instead of considering their specimens abnormal developments of existing species. From the drawings it will be seen of how little value the number and distribution of the arms can be for specific separation. Many of Miller's species rest entirely upon the number of arms. His *A. Indianensis* and *A. Gorbyi* agree in every essential point with the description of *A. splendens*, the only distinction being that *A. Gorbyi* has thirteen arms, while the other two have each twelve arms.† *A. Blairi* is described as a distinct species because it has nine instead of ten arms, which is caused by one of the arms of the anterior ray remaining undeveloped.‡ The only claim *A. profundus* has to recognition as distinct species is the fact that it has fourteen arms, which the author thinks of specific importance. *A. tugurium* is considered new because it has twelve arms; and *A. arcula* with ten arms,§ *A. Iowensis* with fifteen arms and *A. Keokukensis* ‖ with sixteen arms are classed as new species for that reason

* In counting the arms I begin at the left posterior ray (ventral side up) and count toward the right. Smaller figures denote smaller arms.

† Rep. Geol. Surv. Ind. **16:** 340. *pl. IV. f. 1, 2.* — Rep. Geol. Surv. Ind. **17:** 663. *pl. VIII. f. 5;* 664. *pl. VIII. f. 9.*

‡ Rep. Geol. Surv. Ind. **18:** 275. *pl. III. f. 12–14.*

§ Bull. Ill. State Mus. Nat. Hist. 6: 26. *pl. III. f. 1–3;* 28. *pl. III. f. 4–6;* 30. *pl. III. f. 7–8.*

‖ Bull. Ill. State Mus. Nat. Hist. 12: 5. *pl. I. f. 1–3;* 7. *pl. I. f. 4–6.*

only. If we examine the way in which extra arms arise, the folly of considering the number of arms important becomes still more apparent. In rays having regularly three arms, the third arises from a tertiary radial which cuts off the upper angles of the secondary radials. If this plate should divide vertically, forming two tertiary radials, then an arm would spring from each of these two tertiary radials, and there would be four arms to that ray. Increase in the number of arms seems to be due solely to the dividing and cutting off of the sides of the plates. Injury to some of the plates where arms were to form would prevent the further growth of the arm and leave it undeveloped. Such a case I have shown at Fig. 2, where the middle anterior ray started to produce a second arm. The size of the arms and the number of joints are worthless as features of classification, as they are preserved in comparatively few specimens and represent only the age of the animal. The only way in which the number of joints could be of value is, if there were a certain definite number of joints to the inch for each species.

The pentamerous arrangement of the parts is the rule throughout the sub-kingdom of the Echinodermata, but we cannot find another division in the whole animal kingdom so subject to abnormal development. In addition to the above examples of abnormity, I will mention a few striking instances of its occurrence in other families, as examples of deviation from the regular pentamerous type are not uncommon. In Bulletin 3 of the Illinois State Museum of Natural History, on page 19, in a comparison between *Batocrinus facetus* and *B. Lyonanus*, we find the following statement: "In *Batocrinus facetus* the three-armed series is on the right of the azygous side, in this it is on the left. In that species, there are four regular interradials and eleven azygous plates, in this species there are three regular interradials and six azygous plates." In the same Bulletin the following remarks are found in the description of *Zeacrinus bellulus:* "This species bears some resemblance to *Cyathocrinus maniformis* of Yandell and Shumard which has generally been referred to *Zeacrinus*. In that species the subradials are long and abruptly bend into the columnar cavity and upward so as to form a convex rim for the base of the calyx and show the upper part of the plates in a lateral view; in this species the columnar depression is much smaller and the subradials are comparatively shorter and only slightly convex so as to form a somewhat truncated base to the calyx and to show only the superior angles of the plates in a lateral view. The first radials are comparatively shorter and the second radials comparatively longer, and the plates more convex in this species than they are in *Z. maniformis.* The arms in this species are more fusiform than in *Z. maniformis.* In that species there are only nine arms." On page 37, in describing *Z. nitidus*, Miller says, "*Z. maniformis* has proportionally a longer and more globose calyx and much longer arms than our species. The second radials in our species are much more constricted on the sides than they are in *Z. maniformis*, and we are led to infer, from the figure, that it had ten arms while our species has only nine." In a description of *Zeacrinus cylindricus* this statement is made: "This species has been confounded with *Z. maniformis* by some collectors, but in that species the basal plates are hidden by the column, the body is shorter, and there are only nine arms, as the radial series opposite the azygous area bears only a single arm." The distinguishing features of *Batocrinus prodigialis* are given as follows: "This species is distinguished from *B. Yandelli*, which it most resembles, by having twenty-five instead of twenty-one or twenty-two arm openings to the vault, and by having one more regular interradial in each area and one or two more azygous plates."

It seems very arbitrary to make a new species because a specimen has nine instead of ten arms, or has three arms on the right of the azygous side instead of the left, or four regular interradials and eleven azygous plates instead of three regular interradials and six azygous plates, or because the basals are hidden by the column, or because the basals instead of being five, which is the typical number, have become three or two by concrescence. With regard to the description of *Batocrinus prodigialis* I will say that it agrees in every essential point with Shumard's *Actinocrinus Yandelli.** I

* Transactions of The Academy of Science of St. Louis. **1**: 76. *pl. I. f. 4, a, b.*

have examined the specimen from which Shumard made his description and am at a loss to see any difference. The specimen, which is now in the collection of the Washington University, was found at Button Mould Knob in Kentucky, the same locality which Miller mentions for his specimen. Because of the possession of one more arm *Zeacrinus bellulus* is separated from *Zeacrinus maniformis*, which was described by Hall in 1858* as having nine arms which he distinctly states is probably accidental.†

Besides the foregoing reasons for reducing the existing number of species, the following characteristics will help to prove my assertions: —

(a) *Concavity of the base.* — Messrs. Wachsmuth and Springer‡ state that "the Keokuk species without exception are deeply concave, in the basal regions," but I have found all possible gradations from an almost flat basal region to a deeply concave disk. *A. Whitfieldi* is so deeply concave, that when the body is placed upon a level surface, it rests upon the first brachials. In *A. tuberosus* and *A. Americanus* the concavity involves the entire radial series of the plates; in *A. splendens* it extends to the top, and in *A. nodulosus* to the middle of the first distichals; in *A. Wortheni*, to the second costals; in *A. nodosus* and *A. conicus*, to the first costals, and in *A. crassus* it is almost flat. The difference in the concavity is such a gradual variation, that it is impossible to state the extent of concavity permissible for a certain species.

(b) *Horizon and locality.* — A great many of the species recently described were collected at the same place and from the same geological formation. From Charlestown, Indiana, Miller alone described thirty-five new species of *Dolatocrinus*

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* Geol. Rep. Iowa. 1^2: 682. *pl. 25. f. 8.*

† For further examples of abnormal development see Bull. Ill. State Mus. Nat. Hist. 3: 19, 35, 36, 37, 46; 5: 39, 53; 6: 16; 7: 6, 8, 19, 21, 22, 25, 28, 29, 31, 40, 63, 67; 8: 6, 8, 9, 10. — Trans. and Proc. New Zealand Institute. 1894. **27**: 194–208. *pl. X, XI, XII,* and *XIII* (in part). — Quarterly Journal Geological Society. 45^1. No. 177: 149–171. *pl. VI.* (1889); **38.** (1882). — G. Boehm. Zeitschrift der Deutschen geologischen Gesellschaft 43^3. Uber eine Anomalie im Kelche von *Millericrinus mespeliformis.* — Quenstedt. Petrefactenkunde Deutschlands. **4**: 328. — P. de Loriol. Mémoires de la Société Paléontologique Suisse. **4.**

‡ Revision Palaeocrinoidea. Part II. 109.

as occurring in the Hamilton Group. From Sedalia, Mo., he described twenty-six Batocrini from the Burlington Group, thirteen Platycrini from the Chouteau limestone and twenty-two Platycrini from the Burlington; from Burlington, Iowa, nineteen species of *Batocrinus* from the Burlington limestone; and from Boonville, Mo., twenty-one species of Batocrinus from the Keokuk formation. Following is a list of the species described by Miller from the different localities.

CHARLESTOWN, IND. — HAMILTON GROUP.

Dolatocrinus aureatus.
Dolatocrinus bulbaceus.
Dolatocrinus lineolatus.
Dolatocrinus ornatus, var. *asperatus.*
Dolatocrinus spinosus.
Dolatocrinus stellifer.
*Dolatocrinus venustus.**
Dolatocrinus amplus.†
Dolatocrinus bellulus.
Dolatacrinus corporosus.
Dolatocrinus exornatus.
Dolatocrinus Hammelli.
Dolatocrinus pulchellus.
Dolatocrinus vasculum.‡
Dolatocrinus nodosus.
Dolatocrinus sacculus.
Dolatocrinus salebrosus.§
Dolatocrinus aplatus.
Dolatocrinus argutus.
Dolatocrinus bellamgosus.
Dolatocrinus caelatus.
Dolatocrinus Charlestownensis.
Dolatocrinus Indianensis.‖
Dolatocrinus arrosus.
Dolatocrinus asper.
Dolatocrinus aspratilis.
Dolatocrinus basilicus.
Dolatocrinus cistula.
Dolatocrinus dispar.
Dolatocrinus dissimularis.
Dolatocrinus laguncula.
Dolatocrinus Lyoni.
Dolatocrinus peculiaris.
Dolatocrinus preciosus.¶
*Dolatocrinus neglectus.***

SEDALIA, MO. — BURLINGTON GROUP.

Batocrinus aequalis.
Batocrinus aspratilis.
Batocrinus laetus.
Batocrinus scyphus.††
Batocrinus formaceus.
Batocrinus imparilis.

* Bull. Ill. State Mus. Nat. Hist. 4.
† Bull. Ill. State Mus. Nat. Hist. 5.
‡ Bull. Ill. State Mus. Nat. Hist. 6.
§ Bull. Ill. State Mus. Nat. Hist. 7.
‖ Bull. Ill. State Mus. Nat. Hist. 8.
¶ Bull. Ill. State Mus. Nat. Hist. 9.
** Bull. Ill. State Mus. Nat. Hist. 12.
†† Bull. Ill. State Mus. Nat. Hist. 3.

Batocrinus incultus.
Batocrinus insperatus.
*Batocrinus planus.**
Batocrinus argutus.
Batocrinus asper.
Batocrinus basilicus.
Batocrinus folliculus.
Batocrinus germanus.
Batocrinus Jessieae.
Batocrinus nanus.
Batocrinus proximus.†
Batocrinus Pettisensis.
Batocrinus regalis.‡
Batocrinus repertus.
Batocrinus Sedaliensis.
Batocrinus subaequatus.
Batocrinus subcitulus.§
Batocrinus Blairi.
Batocrinus Brittsi.
Batocrinus comparilis.‖
Platycrinus modestus.
Platycrinus semifusus.
Platycrinus sulciferus.
Platycrinus tugurium.¶
Platycrinus concinnulus.
Platycrinus formosus, var. *approximatus.*
*Platycrinus subscitulus.***
Platycrinus acclivus.
Platycrinus amabilis.
Platycrinus batiola.
Platycrinus Blairi.
Platycrinus Broadheadi.
Platycrinus carchesium.
Platycrinus concinnus.
Platycrinus Gorbyi.
Platycrinus lautus.
Platycrinus occidentalis.
Platycrinus pulcellus.
Platycrinus rotundus.
Platycrinus Sampsoni.
Ptatycrinus sulcatus.††

SEDALIA, MO. — CHOUTEAU GROUP.

Platycrinus cortina.‡‡
Platycrinus casula.
Platycrinus clinatus.
Platycrinus formosus.
Platycrinus germanus.
Platycrinus Missouriensis.
Platycrinus Pettisensis.§§
Platycrinus absentivus.
Platycrinus aequiternus.
Platycrinus allophylus.
Platycrinus annosus.
Platycrinus ollicula.‖‖
Platycrinus Chouteauensis.
Platycrinus Colletti.¶¶

* Bull. Ill. State Mus. Nat. Hist. 7.
† Bull. Ill. State Mus. Nat. Hist. 8.
‡ Bull. Ill. State Mus. Nat. Hist. 9.
§ Bull. Ill. State Mus. Nat. Hist. 10.
‖ Rep. Geol. Surv. Ind. 18.
¶ Bull. Ill. State Mus. Nat. Hist. 7.
** Bull. Ill. State Mus. Nat. Hist. 9.
†† Bull. Geol. Surv. Mo. 4.
‡‡ Bull. Ill. State Mus. Nat. Hist. 5.
§§ Bull. Ill. State Mus. Nat. Hist. 7.
‖‖ Bull. Geol. Surv. Mo. 4.
¶¶ Rep. Geol. Surv. Ind. 18.

BURLINGTON, IOWA. — BURLINGTON GROUP.

Batocrinus nitens.	*Batocrinus levigatus.*
*Batocrinus spurius.**	*Batocrinus levis.*
Batocrinus Albersi.	*Batocrinus politus.*
Batocrinus approximatus.	*Batocrinus remotus.*
Batocrinus cognatus.	*Batocrinus repositus.*
Batocrinus complanatus.	*Batocrinus saccellus.*
Batocrinus consanguineus.	*Batocrinus speciosus.*
Batocrinus enodis.	*Batocrinus subovatus.*
Batocrinus glaber.	*Batocrinus subrotundus.*
Batocrinus insolens.	Two abnormal species.†

BOONVILLE, MO. — KEOKUK GROUP.

Batocrinus Broadheadi.	*Batocrinus veterator.*
Batocrinus heteroclitus.	*Batocrinus vetustus.*
Batocrinus ignotus.	*Batocrinus vicinus.*‡
Batocrinus inconsuetus.	*Batocrinus delicatulus.*
Batocrinus inopinatus.	*Batocrinus parilis.*
Batocrinus insuetus.	*Batocrinus stelliformis.*
Batocrinus modestus.	*Batocrinus strenuus.*§
Batocrinus nitidulus.	*Batocrinus Boonvillensis.*
Batocrinus peculiaris.	*Batocrinus Gorbyi.*
Batocrinus polydactylus.	*Batocrinus Gurleyi.*
Batocrinus procerus.	*Batocrinus mediocris.*
Batocrinus Sampsoni.	*Batocrinus pulchellus.*
Batocrinus serratus.	*Batocrinus venustus.*‖
Batocrinus venustulus.	*Batocrinus divalis.*¶

The impossibility of such a large number of new species being found in a comparatively small space becomes an overwhelming fact, when we consider the distribution of plants and animals. Nature has never been known to confine such an incredible number of species at one spot. Nothing like it is found in the distribution of plants and animals of the pres-

* Bull. Ill. State Mus. Nat. Hist. 9.
† Bull. Ill. State Mus. Nat. Hist. 10.
‡ Bull. Ill. State Mus. Nat. Hist. 7.
§ Bull. Ill. State Mus. Nat. Hist. 9.
‖ Bull. Geol. Surv. Mo. 4.
¶ Rep. Geol. Surv. Ind. 18.

ent time, and we may safely assume that the same rules of distribution which exist to-day existed during the geological ages. From Florissant, Colorado, a place famous for the great abundance of fossil plants and insects found there, 213 species of fossil plants have been enumerated.* Of these the Family Myricaceae contains the largest number, thirteen in all. More than one hundred and seventy species of Formicidae have been described from different localities, the largest number, thirty-seven, from Radoboj.

(c) *Possible influence of light.* — The aërial parts of plants are directed largely under the influence of light, the stem and petioles curving toward the light and the blades standing at right angles to the rays of light. *Gorgonia* shows the same tendency to develop more on the side toward the light, and in a number of Blastoids the whole body leans considerably to one side, suggesting more rapid development toward the light. In a number of Crinoids the same asymmetry of the calyx may be seen, which may be due to heliotropism. As to the extent of this influence it is impossible to come to any definite conclusions at the present time, but a thorough study of more material may lead to more tangible results.

(d) *Effects of injury.* — In describing *Batocrinus insuetus*† Miller gives as one of the distinctive characters the balloon-shaped bulb terminating the proboscis. This is as far as I know the only one found having this feature, which alone should have made the author very cautious about describing it as a new species. In all probability the proboscis was injured early in its growth, and as a result developed a balloon-shaped growth. There is no more reason for making a new species based on this character, than there would be for creating a new species of oak, because the tree had a part of its trunk expanded into a big tuber-like growth. Very many Crinoid stems show the marks of injury and an increase in size at those points.

The mistake of considering the variations in the different parts as of specific importance has led to the creation of many

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* Trans. The Academy of Science of St. Louis. 8: 161-188.

† Bull. Ill. State Mus. Nat. Hist. 7: 14. *pl. I. f. 8, 9.*

synonyms. Forty-two species have been described which can easily be reduced to ten. The following is a list of the species with their synonyms and geological formations.

I.

1892.	*Agaricocrinus Chouteauensis*, Miller.	Chouteau.
1892.	*Agaricocrinus Blairi.*	Chouteau.
1892.	*Agaricocrinus germanus.*	Chouteau.
1892.	*Agaricocrinus Sampsoni.*	Chouteau.

II.

1858.	*Agaricocrinus brevis*, Hall.	L. Burlington.
1858.	*Agaricocrinus pyramidatus.*	L. Burlington.
1858.	*Agaricocrinus stellatus.*	L. Burlington.
1860.	*Agaricocrinus corniculus.*	L. Burlington.
1860.	*Agaricocrinus geometricus.*	L. Burlington.
1861.	*Agaricocrinus fiscellus.*	L. Burlington.
1861.	*Agaricocrinus corrugatus.*	L. Burlington.

III.

1896.	*Agaricocrinus Adamsensis*, Miller and Gurley.	Burlington.
1896.	*Agaricocrinus Hodgsoni.*	Burlington.

IV.

1896.	*Agaricocrinus Illinoisensis*, Miller and Gurley,	Burlington.

V.

1861.	*Agaricocrinus inflatus*, Hall.	Burlington.
1861.	*Agaricocrinus planoconvexus.*	Burlington.
1891.	*Agaricocrinus decornis.*	Burlington.
1897.	*Agaricocrinus convexus.*	Burlington.

VI.

1861.	*Agaricocrinus ornotrema*, Hall.	U. Burlington.
1897.	*Agaricocrinus bellatrema.*	U. Burlington.
1897.	*Agaricocrinus bellatrema*, var. *major*.	U. Burlington.

VII.

1861. *Agaricocrinus gracilis*, Meek and Worthen. U. Burlington.

VIII.

1860. *Agaricocrinus Coreyi*, Lyon and Casseday, Keokuk.
1882. *Agaricocrinus Springeri.* Keokuk.

IX.

1858. *Agaricocrinus Wortheni*, Hall. Keokuk.
1858. *Agaricocrinus Whitfieldi.* Keokuk.
1897. *Agaricocrinus conicus.* Keokuk.

X.

1855. *Agaricocrinus Americanus*, Roemer. Keokuk.
1858. *Agaricocrinus tuberosus.* Keokuk.
1858. *Agaricocrinus bullatus.* U. Burlington.
1860. *Agaricocrinus pentagonus.* U. Burlington.
1861. *Agaricocrinus excavatus.* U. Burlington.
1869. *Agaricocrinus nodosus.* U. Burlington.
1881. *Agaricocrinus crassus* (?) Keokuk.
1881. *Agaricocrinus elegans.* Keokuk.
1890. *Agaricocrinus Macadamsi.* Keokuk.
1890. *Agaricocrinus nodulosus.* Keokuk.
1890. *Agaricocrinus splendens.* Keokuk.
1891. *Agaricocrinus dissimilis.* Keokuk.
1891. *Agaricocrinus Gorbyi.* Keokuk.
1891. *Agaricocrinus Indianensis* Keokuk.
1895. *Agaricocrinus arcula.* Keokuk.
1895. *Agaricocrinus profundus.* Keokuk.
1895. *Agaricocrinus tugurium.* Keokuk.
1897. *Agaricocrinus Americanus*, var. *tuberosus.* Keokuk.
1897. *Agaricocrinus Iowensis.* Keokuk.
1897. *Agaricocrinus Keokukensis.* Keokuk.
1897. *Agaricocrinus nodulosus*, var. *Macadamsi.* Keokuk.

In conclusion I will offer a few suggestions as to the features which seem proper for specific separation. In the preceding pages I have pointed out the great deviations from the pentamerous arrangement in the number and size of the interbrachials, costals, and distichals, and in the number and distribution of the arms. A natural classification rests upon those prevailing characters which are most constant. This fact points out at once the fallacy of adopting the interbrachial plates, costals, distichals or arms as distinctive features. The best characters for specific separation are (a) the general aspect of the plates, (b) the external ornamentation of the plates, and (c) the anal area. The geological formation is also of value, as we may assume with perfect safety that fossils found in the Chouteau Group belong to different species from those found in the Burlington or Keokuk. Specimens from the Burlington in general appearance look very different from those of the Keokuk. Chouteau and Burlington specimens have ten arms, a deviation from the number being rare. In the Keokuk we see a tendency toward abnormal development appearing in the number of arms. The regular Keokuk species has twelve arms, which in itself is a departure from the pentamerous arrangement. Deviations from that number and in the distribution among the rays are very frequent as I have pointed out before. Finding the pentamerous rule tolerably well preserved in the Chouteau and the Lower Burlington Groups, with an increase in the amount of deviation from it throughout the Upper Burlington and the Keokuk, proves conclusively that the tendency was toward abnormal development.

Diagnoses of Species.

Agaricocrinus Chouteauensis, Miller.

Dorsal side flat or very little concave in the region of the basal plates. Ventral side low, covered with small slightly convex plates. Surface of the plates granular, rarely smooth. Anal orifice small. — Geological formation. Chouteau.

Agaricocrinus brevis, Hall.

Orals distinctly convex, the interambulacrals almost flat. Posterior oral sharply conical. Plates of the dorsal cup below the arm regions thickened, rising above the suture lines in nodose or tuberculose extensions with short ridges extending to the sides of the plates, where they meet with the ridges from adjoining plates. Surface granulose. Anal area formed of numerous rows of small plates with a distinct groove at each side. — Geological formation. Burlington, especially Lower Burlington.

AGARICOCRINUS ADAMSENSIS, Miller and Gurley.

Plates thick, part of them subspinous. The first primary radials are sculptured so as to be pyramidal or subspinous. Ventral side moderately convex, covered with large plates and a very large posterior oral which may be formed into a conical spine. The anal area is elliptical with no indications of an orifice or only a very small opening on top partly surrounded by small plates.— Geological formation. Burlington.

AGARICOCRINUS ILLINOISENSIS, Miller and Gurley.

Ventral disk low, most convex toward the middle. One large convex central oral, otherwise the plates are small and very little convex. Plates thick, smooth or granular. Anal area not elevated or a tumid swelling, but composed of small flat plates. — Geological formation. Burlington.

AGARICOCRINUS INFLATUS, Hall.

Plates of the dorsal cup flat, radials and first interbrachials sometimes a little concave. Ventral disk highly elevated, plates all flat, except the posterior oral which is more or less nodose. Ventral disk strongly inflated at the anal area which is composed of almost flat pieces, with a shallow groove at each side in some.— Geological formation. Burlington.

AGARICOCRINUS ORNOTREMA, Hall.

Plates of the dorsal cup flat. Radial dome plates highly convex. Posterior side of the ventral disk inflated and protruding. The middle portion of the inflation consists of an ovoid flattened area, covered by small plates which are surrounded by moderately large, strongly nodose or subclavate pieces.— Geological formation. Upper Burlington.

AGARICOCRINUS GRACILIS, Meek and Worthen.

First costals, first interbrachials and second anal plates abruptly bent upward and swollen to form a circle of nodes at the lower margin of the calyx. Surface of the calyx finely granulose and convex enough to bring out the suture lines. Anal area almost flat. — Geological formation. Upper Burlington.

AGARICOCRINUS COREYI, Lyon and Casseday.

All plates of the body tumid with abruptly raised transverse ridges on each plate. Surface smooth. Anal area an elongate distinctly rounded area, composed of small, smooth, irregular pieces. — Geological formation. Keokuk.

AGARICOCRINUS WORTHENI, Hall.

Plates within the concavity perfectly flat, others slightly convex. Orals and radial dome plates large with rounded nodes. Intervening pieces small and only slightly convex. Surface finely granulo-striate. Anal area perfectly flat. There is no anal ridge, the plates of the posterior area growing smaller as they approach the anus. — Geological formation. Keokuk.

AGARICOCRINUS (AMPHORACRINUS) AMERICANUS, Roemer.

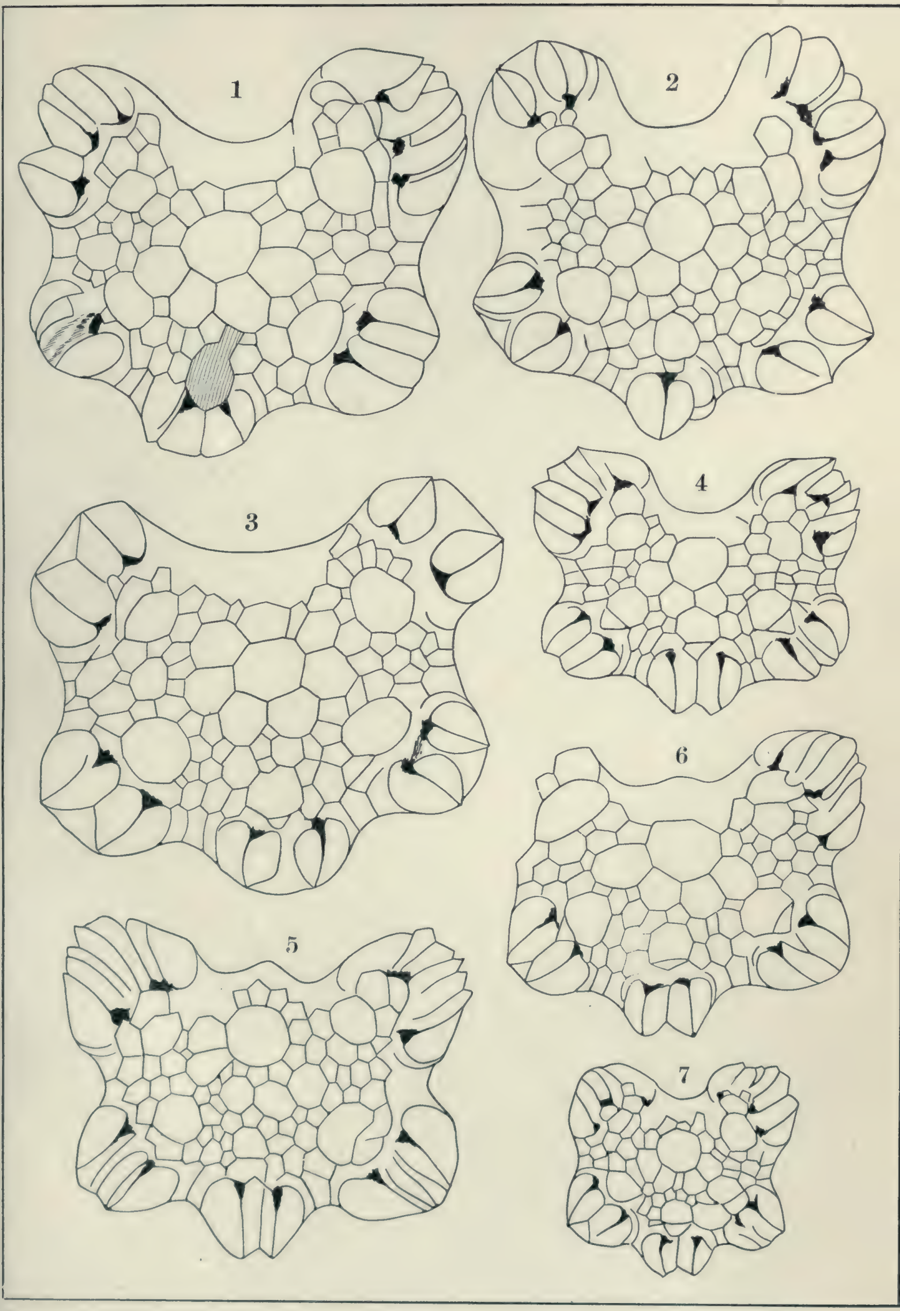
Plates within the concavity flat or slightly convex, while the others are more or less convex and sometimes covered with indistinct transverse angularities. Plates of the ventral side highly convex, except the interambulacral pieces which are much smaller and almost flat. Orals and radial dome plates large and tuberculose. Surface granular or granulose striate toward the margin of the plates. Anal area abruptly protruding, formed into a large anal process with a broad depression on either side. — Geological formation. Upper Burlington and Keokuk.

EXPLANATION OF ILLUSTRATIONS.

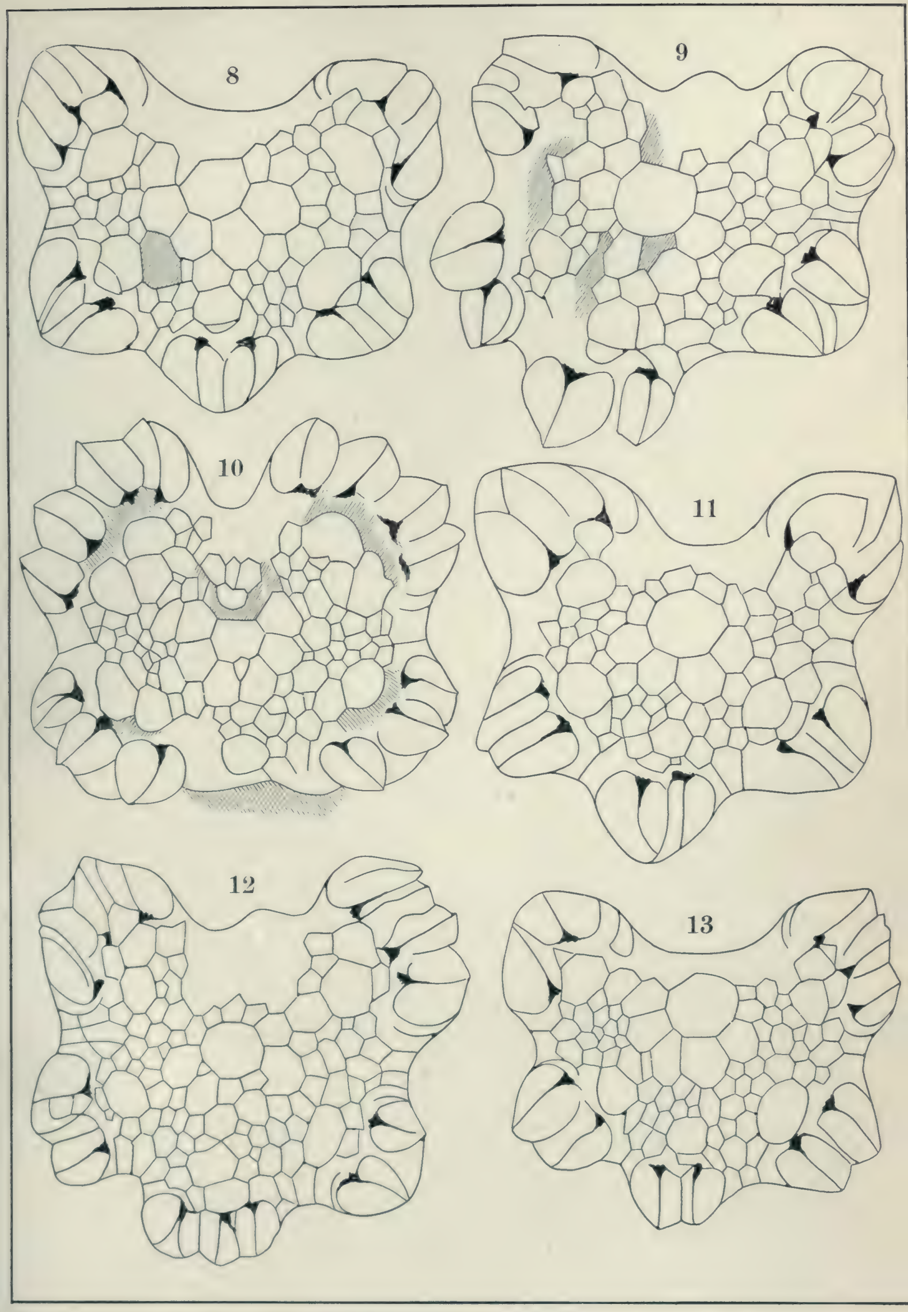
PLATES XVIII–XXI.

All the figures are drawings, by the author, of the ventral side of *Agaricocrinus Americanus*, and show the great variations in the number and distribution of the arms, and in the plates of the tegmen. All the drawings are about natural size and drawn as if the arm bases had been flattened out, regardless of perspective.

Issued May 30, 1900.



AGARICOCRINUS AMERICANUS.



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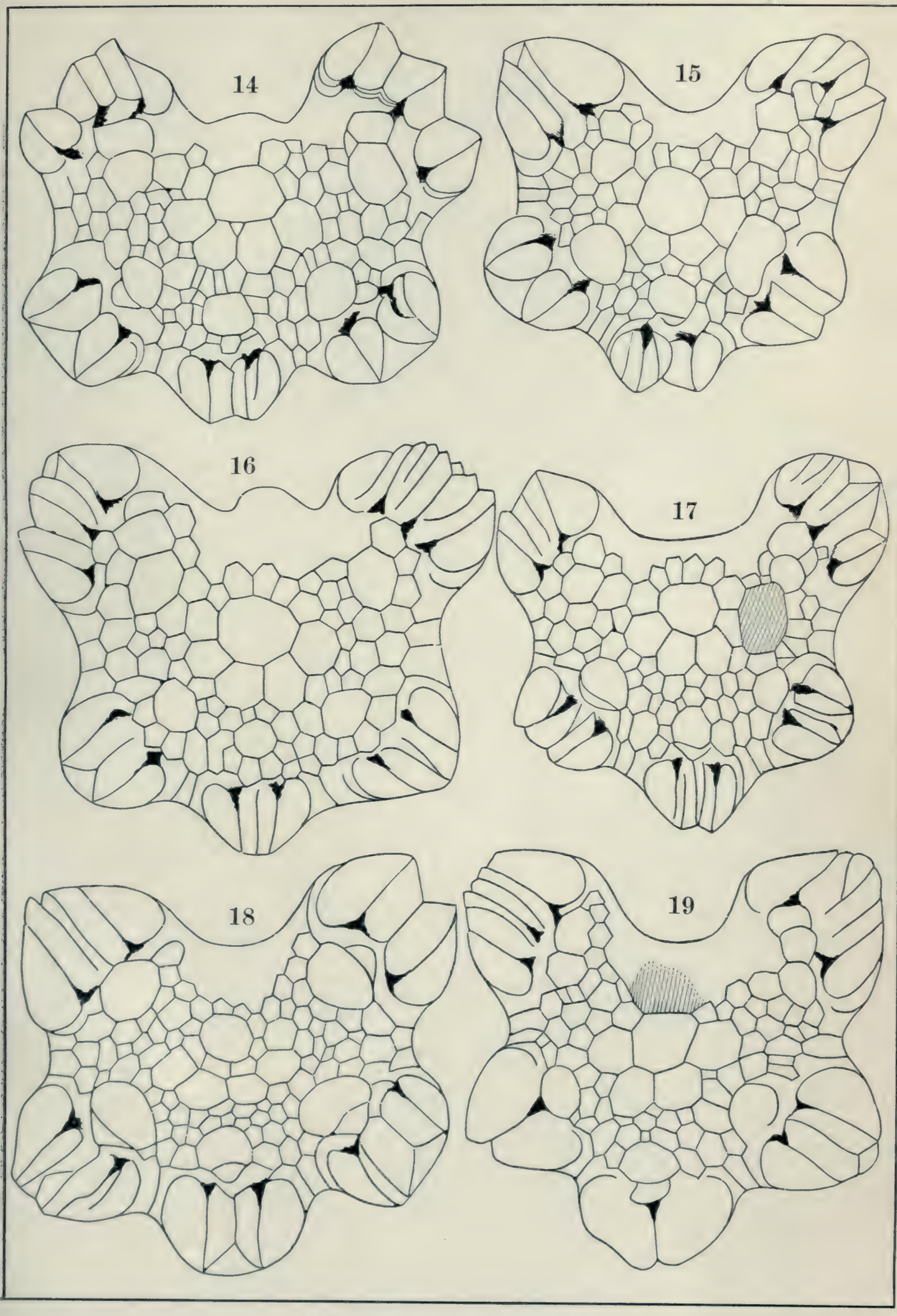

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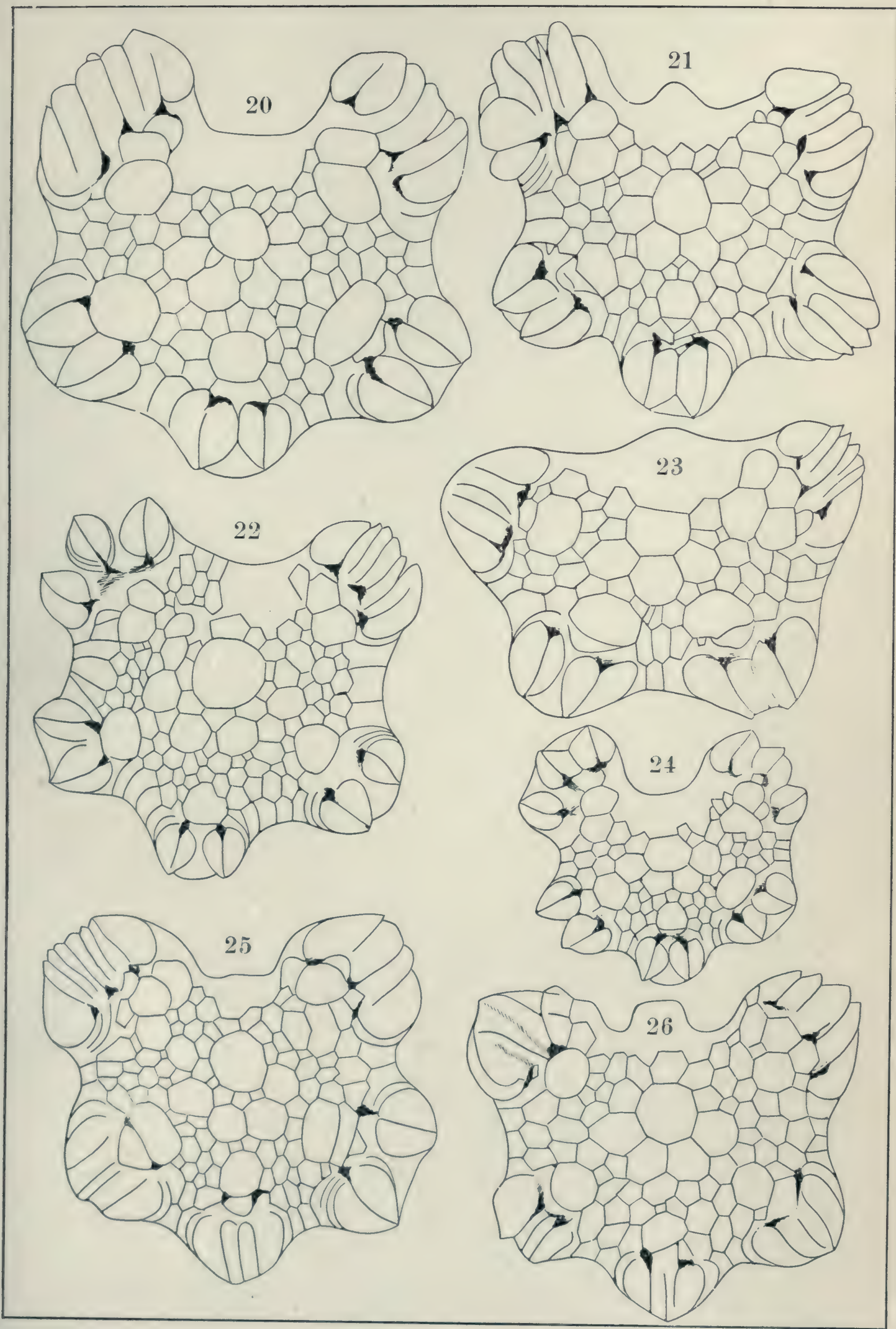

AGARICOCRINUS AMERICANUS.

ORIGINAL CONTRIBUTIONS CONCERNING THE GLANDULAR STRUCTURES APPERTAINING TO THE HUMAN EYE AND ITS APPENDAGES.*

ADOLF ALT, M. D.

PREFACE.

The studies and investigations which are the subject of this paper are the outcome of a desire to have as clear as possible an understanding of the glandular structures appertaining to the human eye and its appendages from personal knowledge.

It took a number of years to accumulate the very numerous specimens, the careful study of which furnished the basis for the descriptions here given. While part of the many eyelids which I have examined were obtained from suitable cases in my own practice, a large number came from the dissecting rooms of the Beaumont Hospital Medical College of this city through the kindness of Dr. R. W. Baker, the demonstrator of anatomy in this institution. Of necessity a great part of this anatomical material was of a pathological character, and it has, therefore, served for other studies as well.

As it seemed to me that the text-books which I know of, with but few exceptions, deal in a very insufficient manner with this interesting subject, I have thought it might be of some interest to place the results of my own investigations in this direction before the ophthalmic public. This may, perhaps, prove the more interesting, since by the efforts of numerous foreign ophthalmic surgeons, and in this country notably of Dr. C. R. Holmes of Cincinnati † the old operation of the removal of the lacrymal glands for incurable lacryma-

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* Presented by title to The Academy of Science of St. Louis, May 21, 1900.

† Archives of Ophthalmology. 28 : 1.

tion has of late been reintroduced and has become a legitimate surgical procedure.

The investigations herein recorded may claim to be original in so far as they were made, in a sense, as if I had known nothing of the literature on the subject. This was in reality the case with some of the more recent monographs which I did not and had no chance to consult until my researches, at least as far as my material would allow me, were finished.

The illustrations, except the three last ones, which are more or less schematic drawings, are made from photographs I took of my own specimens.

THE ORBITAL, PALPEBRAL AND CONJUNCTIVAL LACRYMAL GLANDS.

The lacrymal gland is usually spoken of as consisting of two separate parts, one the so-called orbital lacrymal gland and the other termed the inferior, palpebral, conjunctival or accessory lacrymal gland.

The orbital lacrymal gland, as its name denotes, is situated, at least to its greatest extent, within the orbital cavity. There it is located in the fovea lacrymalis which lies right behind the outer upper bony orbital margin in the processus zygomaticus of the frontal bone. Its anterior end usually slightly protrudes beyond the bony margin. The gland is held in this position by a connective tissue capsule which is united with the orbital periosteum by means of loosely interwoven trabeculae. This capsule is generally somewhat firmer on the nasal side of the gland.

When this gland is in toto removed from the fovea lacrymalis, its shape is seen to resemble to some extent that of an almond (Fig. 1). It is convex at the orbital surface, and more or less concave at its ocular (lower) side. Its posterior portion is usually thick and rounded, its anterior one thinner and sharper. The posterior part of the gland may, when it is well developed, reach back into the orbit about as far as the anterior third of its depth. The nasal edge usually reaches to the temporal margin of the superior rectus muscle.

However, the actual measurements of this gland, like those of other glands, are subject to great variations. As an interesting fact, I may say, that in the Negro I have found this gland to be as a rule larger than in the Caucasian. I have seen it often to be twice as large or even more (Figs. 2, 3).

The orbital lacrymal gland forms a more or less compact glandular body. It consists of a large number of lobules united closely with each other by loose connective tissue in which its ducts and numerous blood vessels lie. These connective tissue trabeculae are united to its capsule.

The gland is of the acinous type and its structure has been correctly likened to that of the serous or salivary glands. The round or oval final acini are situated around and connected with small efferent ducts which, by their union in the direction towards the conjunctiva, form larger and larger excretory ducts. These acini consist of a membrana propria and a lining of cylindrical, or rather, conical secretory epithelial cells, with a large round or oval nucleus near their broader base which are arranged in a circle around a central lumen.

The secretion of this gland is carried to the conjunctival sac by means of a varying number of these excretory ducts which are lined with a cylindrical epithelium. The statement is made by numerous authors, that there are from 6 to 12 such excretory ducts. It does not seem to me that there are so many. I often found one of them, which also seemed to be the longest, to be considerably wider than the others.

These excretory ducts reach the conjunctiva of the fornix by a somewhat bent and wavy course; their external orifices lie in the temporal part of the conjunctival sac near the edge of the tarsal tissue.

Below the orbital lacrymal gland and separated from it by its capsule, the levator palpebrae superioris muscle and Mueller's non-striated muscle, and embedded in the loose connective tissue of the eyelid on the temporal side of the tarsus, lies the inferior or palpebral lacrymal gland (Figs. 1 to 5).

This gland consists of a varying number of smaller and larger lobules which are very much more loosely held together by the intervening connective tissue than those of the orbital gland, and therefore do not form as compact a body.

While this gland is usually thought to lie in the upper eyelid alone, I have in normal lids almost invariably found its lobules to reach downwards through and beyond the outer canthus into the lower eyelid (Figs. 6, 7). The glandular lobules here lie grouped around the temporal and sometimes even the lower edge of the tarsus. Similar lobules of glandular tissue, only still more loosely connected with and further apart from each other, are found in most eyelids to extend from the more compact temporal body of this palpebral glandular system towards the nasal side of the upper eyelid. These more isolated lobules may reach to the middle line of the eyelid and even somewhat beyond it (Figs. 8, 9). They lie in the loose tissue of the fornix of the conjunctiva or a little below it on the palpebral side. The farther away from the outer canthus, the smaller these glandular lobules usually are. Those found in the temporal side of the lower eyelid seem to be of a more uniform size. Yet, there is no absolute rule about this.

It seems that when speaking of the palpebral or inferior lacrymal gland, we have to include all of these separate and so widely dispersed glandular lobules. Their number in the aggregate may well reach up to 40 or more.

The structure of the glandular lobules is exactly the same as that of the orbital lacrymal gland. They differ in no particular. Their numerous efferent ducts, lined with cylindrical epithelium, lead their secretion to the conjunctival sac (Fig. 10). The statement has often been made and repeated, that the ducts of these glands are taken up by those of the orbital lacrymal gland around which, in part, they are grouped, before reaching the conjunctival surface. Whether this happens often, I cannot tell definitely in spite of my numerous specimens; but it may occasionally be the case. I find, that most frequently several of these lobules have an excretory duct in common, which runs separately from the excretory ducts of the orbital lacrymal gland to the conjunctiva. Such a duct has generally a wavy course and does not reach the conjunctiva by the shortest route (Figs. 10 to 16). The more widely separated and the totally isolated glandular lobules in the lower eyelid and those glands which extend in the upper eyelid towards its middle line, must of necessity have their ducts apart from those of the orbital lacrymal gland, as they lie so far removed from them. The external orifices of these ducts lie in the upper conjunctival fornix and usually form a row, being arranged side by side. I may state here, that these excretory ducts pierce the conjunctival surface generally at a more or less acute angle in a downward direction, so that the upper lip overhangs the orifice (Figs. 11, 14).

Even in what appear to be perfectly normal conjunctivae, the orfiices of the ducts are frequently surrounded by a dense lymphoid infiltration in the adjoining tissue. This infiltration is frequently so dense that on surface specimens it may hide the openings. This condition may, perhaps, be the explanation for the repeated statements that in the normal conjunctiva of man lymph-follicles could be found. I here repeat the statement which I have made on other occasions, that, like Waldeyer, I have never found a true lymph-follicle in the human conjunctiva.

From the foregoing description it is apparent that a very large, though varying, amount of glandular tissue, of identically the same structure and most probably the same function as the orbital lacrymal gland, is situated in the temporal half of the eyelids above, respectively below, the fornix conjunctivae. The secretion of all of these glands, combined with that of the orbital lacrymal gland, is discharged into the conjunctival sac and, flowing over the surface of the eyeball, keeps it and the inner surfaces of the eyelids moist.

Yet, even a careful removal of all of this glandular tissue does not render the surface of the eyeball dry. There must, therefore, be still other glandular structures, which supply such a moistening liquid, and, in reality, a number of such glands do exist.

Almost without exception I find one such gland, consisting of 2 or 3, seldom 4 lobules, near the inner canthus in the nasal part of the upper eyelid, or a little higher up in the conjunctiva near the fornix (Figs. 17 to 20); another one, consisting usually of 2 lobules, I find in the nasal conjunctiva of the lower eyelid, below the lacrymal caruncle (Figs. 21, 22), and frequently one in the temporal side of the lower eyelid somewhat nasally rem ved from the palpebral lacrymal gland.

When studying horizontal sections through the eyelids such little glands are sometimes found, also, to lie close to the temporal and nasal edges of the tarsus of the upper as well as the lower lid, and partly in the ocular conjunctiva. They are formed of one or two minute glandular lobules. All of these glands are of exactly the same histological structure as those generally recognized as lacrymal glands. Their excretory ducts, from their situation, are rather short. They, also, are lined with cylindrical epithelium. Their external orifice lies usually in the palpebral, sometimes in the ocular conjunctiva (Figs. 23 to 25).

There is no reason, as far as I can see, why these small isolated acinous glands should not also be looked upon as lacrymal glands, as they differ in no way histologically from them. The difference in size is the only one I can recognize.

The presence of these glands alone, then, could explain why, after the operative removal or the destruction of the orbital and the larger palpebral lacrymal glands in the temporal half of the eyelids, the surfaces of the eyeball and eyelids do not become dry. It is, furthermore, clear that when a chronic inflammation, involving the whole of the conjunctiva, gradually leads to its shrinkage and to the consequent obliteration of the excretory ducts and secondarily to atrophy of all these glands (and of some to be described presently), as for instance trachoma, xerophthalmus must result.

GLANDS SITUATED IN THE TARSAL TISSUE OF THE EYELIDS.

The tarsal tissue proper of the eyelids contains two forms of glands, namely, the so-called Meibomian glands and the acino-tubular (Waldeyer) glands.

The Meibomian glands are found in the upper lid to be about 30 in number, while in the lower lid they are only about 20. There are, however, individual variations as to these numbers. They are long, slender glandular structures, somewhat resembling the pancreatic glands, consisting each one of a central duct to which are attached numerous round, vesicle-like acini (Fig. 26). These central ducts never quite reach the upper (in the lower eyelids the lower) edge of the tarsus. The acini begin somewhat removed from the external orifice of this central duct and sit upon it very much like grapes on the central stem. They form usually four rows around it, one on the posterior and one on its anterior surface, one on its nasal and one on its temporal side (Figs. 27, 28). The external orifices of the excretory ducts lie side by side at the free edge of the lid behind the lashes. The dermal epithelium reaches inwards into these ducts for some distance, as is particularly well shown in the eyelids of the Negro (Fig. 26).

The acini of these glands as well as their ducts are lined with several layers of flat polygonal epithelial cells. These continually undergo a fatty degeneration and thus form a sebaceous secretion which renders the lidmargins fatty and thus helps to retain the tear-fluid within the conjunctival sac. In their structure these glands differ in no way from the sebaceous glands of the skin; they differ only in size.

The length of the individual Meibomian glands varies according to the height of the tarsal tissue. Thus, the longest ones lie in the middle line of the eyelid, and from there they grow gradually shorter towards both canthi. The most nasally or temporally situated ones often consist only of the central duct and two or three acini.

I can find only one layer of Meibomian glands, and all statements, referring to two or even more layers, are undoubtedly due to oblique sections. In a general way these glands run parallel to each other and at right angles to the lidmargin. Yet, deviations from this rule are not uncommon (Fig. 28).

The second kind of glands, the acino-tubular ones (Waldeyer), are usually drawn and described as lying solely in the temporal part of the tarsus above (in the lower lid below) the Meibomian glands (Fig. 29 to 31). This seems to be their most frequent location, or at least, they seem to be generally best developed in this portion of the tarsus. They are however, at least in the upper eyelid, quite frequently found to be located, also, near and in the middle line (Figs. 23 to 25), and sometimes, but rarely so, near the nasal edge of the tarsus (Fig. 32). While, as a rule, they are situated between the apex of the Meibomian glands and the upper (in the lower eyelid the lower) edge of the tarsus, they are not at all infrequently found to reach in between the Meibomian glands and as far down (or up) almost as the orifices of these glands at the lidmargin (Figs. 32 to 35).

The histological structure of these glands is also of the acinous type, and they do not essentially differ from the lacrymal glands, although their appearance and general arrangement are slightly modified by the dense tissue in which they lie embedded (Figs. 36, 37). Their lobules are formed of numerous round and oval acini which consist of a basal membrane lined with cylindrical (conical) cells arranged around a central lumen, with a round or oval nucleus near their base. The small excretory ducts coming from the acini unite into a larger one which is sometimes quite long and to which smaller acini are attached throughout its length, the small ducts of which empty directly into this large duct formed by the union of the ducts coming from the most distant acini. It is probably this arrangement which has led to their being named "acino-tubular" glands. Sometimes, however, and especially when these glands are situated between the Meibomian glands, this excretory duct is but very short. The excretory ducts of the acino-tubular glands are, also, lined with cylindrical epithelium, like those of the lacrymal glands. Their external orifice lies in the palpebral conjunctiva (Figs. 35, 38).

These acino-tubular glands are generally spoken of as muciparous glands. For what reason, I have been unable to determine, and it is not possible to examine their secretion chemically. Their structure as stated, with the slight modification due to density of the tissue in which they lie embedded, corresponds in every respect with the lacrymal glands. The microscopical staining reagents which seem to have a special affinity to mucous substances, as haematoxylin, Bismark-brown, and others, do not stain any part of these glands in particular. Now and then I have found a concretion in the excretory duct of such a gland, but this cannot be taken as proof of their muciparous character, as just such concretions are also found in the ducts of the lacrymal glands (Fig. 39).

GLANDS SITUATED IN THE TISSUE OF THE LIDMARGIN.

In the dense tissue of the lidmargin, in front of the excretory ducts of the Meibomian glands, the cilia or eyelashes are implanted. These short curved hairs form three or four rather irregular rows and emerge from the skin of the anterior part of the lidmargin (Fig. 40). They are more numerous in the upper eyelid than in the lower one, numbering in the former from 100 to 150, in the latter from 50 to 70. These numbers are, of course, only approximately correct. The longest eyelashes lie in the middle line of the lids and from here they grow smaller and smaller in the direction towards the canthi. They are shortlived and drop out when about from 50 to 100 days old. The curvature of the eyelashes of the upper lid is concave upwards and convex downwards, while that of the eyelashes of the lower lid is just the reverse.

Each eyelash is accompanied by sebaceous glands, usually two, not infrequently three and four to one hair. These glands do not differ in any particular from other sebaceous glands of the hair of the skin and, therefore, it is not necessary to give here a special description.

There is, however, another kind of glands situated in the intermarginal tissue of the eyelids, more especially, between the roots of the eyelashes, which is of a somewhat peculiar structure. These glands have been called *modified sweat-glands*, although, as far as I can find, nothing is known concerning the character of their secretion (Figs. 41, 42).

In vertical (sagittal) sections through the whole thickness of the eyelids one or two such glands are usually seen to lie between the roots of two neighboring eyelashes or a little nearer to the lidmargin, sometimes farther inwards between the eyelashes and the tarsal tissue. In horizontal sections (Fig. 43) and sections which are made parallel to the surface of the eyelid, these glands are often found to be very numerous. (I have never succeeded in getting such sections parallel to the surface which would go through the whole width of the eyelid on account of its curvature, but they often comprise about half or a little more of an eyelid. For the same reason, that is, the curvature of the eyelid, these sections can only in an approximate way be said to run parallel to the surface of the eyelid.)

Near the canthi where the eyelashes cease, I find, as a rule, a larger body of these glandular structures lying outside of the last eyelash, temporally as well as nasally.

These peculiar glands usually appear to consist of one or two rows of round or oval vesicle-like acini, which are sometimes quite large, and which probably communicate with each other (Figs. 44, 45). Half a dozen or so of such acini seem to constitute the gland. These usually terminate in one larger, more conically shaped acinus, a collecting chamber, from which the efferent duct of the gland takes its origin. While this arrangement is the one I have almost always found, I have now and then seen a gland which appeared to be altogether tubular, the tube being wound upon itself exactly as is the case with the sweat-glands of the skin (Figs. 42, 46). As this usually occurred in thicker sections it may, perhaps, be that the appearance I have above described, is due to the manner in which the section has cut through the windings of the tube, and that in reality we have to deal altogether with tubular glands. I have been unable to come to a definite conclusion as regards this point.

The efferent duct of these glands usually has a slightly arched course on its way to the lidmargin (Figs. 41, 42). There its orifice lies frequently within the duct of one of the sebaceous glands belonging to an eyelash. There are, however, many exceptions to this general rule, and I have found in almost every eyelid a number of external orifices of efferent ducts of modified sweat-glands which lie separately in the skin of the lidmargin.

The acini of these peculiar glands are lined with a short, almost cuboid cylindrical epithelium ; the epithelial cells lining the efferent ducts appear more flattened.

I have frequently seen a fatty, grumous substance contained in the lumen of the acini of these glands which appeared exactly like the contents found in the acini of the Meibomian glands. Like these it did not take up any stain and it was dissolved and totally disappeared, as soon as the specimen was cleared in oil of cloves. Of course, it is not permissible to conclude from this fact alone that these glands must be looked upon rather as modified *sebaceous* than as modified *sudoriferous* glands. Still, I think this point is worth mentioning. Neither does it seem very apparent, what role a watery secretion should play, when mixed with the fatty secretion of the sebaceous glands of the eyelashes. Furthermore, a watery secretion in this region would very likely lead to the overflow of the tears at the lidmargin, which is evidently not the case.

THE CARUNCULA LACRYMALIS AND THE GLANDS SITUATED IN ITS TISSUE.

The little rounded body of tissue lying at the nasal canthus between and slightly backwards from the folds coming from the upper and lower eyelids, which is called the lacrymal caruncle, consists to a large extent of glandular tissue and bears some small hairs on its surface.

In vertical, as well as in horizontal sections through this body, I find usually three larger sebaceous glands which, except in their smallness, differ in no particular from the Meibomian glands of the eyelids. They have the same central duct and the same acini, only in a more compact arrangement (Fig. 47).

Now and then one or two of the so-called modified sweat-glands are found between them, lying usually in the center of the body of the caruncle. They differ from those found in the tissue of the lidmargin only by being smaller and shorter.

With much more regularity, indeed, almost as a rule, I find one, and quite often two, small glandular bodies of the acinous type situated in the lacrymal caruncle (Figs. 47 to 50). One of these usually lies near the upper and the other nearer the lower edge of the caruncle. They differ in their structure in no way from the acinous glands found in the conjunctiva and eyelids, and are, therefore, probably little lacrymal glands like these. At least they do not react differently against staining reagents and more especially they do not show any staining affinity which would prove that they are of a muciparous character.

Their short excretory ducts are lined with cylindrical epithelium, and their external orifice lies either on the surface of the lacrymal caruncle or in the plica semilunaris.

Aside from these glandular structures, usually some fat-tissue is inclosed in the connective tissue which forms the body of the caruncle. In one case, and in one only, I found a small amount of hyaline cartilage tissue embedded in the loose connective tissue near the lower margin of the lacrymal caruncle and between it and the plica semilunaris (Figs. 51, 52).

THE LACRYMAL DRAINAGE APPARATUS.

The tear fluid which has neither been evaporated nor used up in moistening the surfaces of the eyeball and the eyelids, is drained off into the nose at the nasal angle of the palpebral fissure by means of a special system of draining tubes.

This draining apparatus begins with the lacrymal puncta, two small oval openings which are situated at the apex of the lacrymal papillae. These papillae are little cone-shaped elevations which lie in the lidmargins in line with, and to the nasal side of, the orifices of the Meibomian glands in the tarsal part of the eye-lids. The lower papilla lies, as a rule, a little farther removed temporally from the inner canthus, than the upper one.

From the puncta the lacrymal canaliculi start by which the tear-fluid is carried to the lacrymal sac. Each canaliculus may be divided into two parts, namely, a more or less vertical (Fig. 53) and a more or less horizontal one (Fig. 54). The first part, which is by far the shorter, runs from the lacrymal punctum upwards (in the lower eyelids downwards), and inwards, nearly at a right angle to the lidmargin. It is from 1.5 to 2 mm. long. The second, the so-called horizontal, part, runs in the direction towards the nose until it reaches the lacrymal sac.

Just inwards from its orifice at the lacrymal punctum the vertical part is generally very narrow (Fig. 55), and then widens out more gradually. Where it makes the sudden bend to form the horizontal part, it usually has a diverticle (Fig. 56), which bulges out from its temporal side into the tissue of the eyelid. This diverticle is formed just at the end of the vertical part, and runs in a horizontal direction and is sometimes comparatively large. Quite frequently there is another diverticle in the horizontal part just at its beginning which runs in a more vertical direction.

The horizontal part of the upper canaliculus is about 7 mm. long and that of the lower canaliculus is a little longer. As stated above, the course of this portion of the canaliculi is not in reality horizontal, as the two gradually bend toward each other. Moreover this part of the canaliculi does not run in a straight line, so to speak, but is quite wavy, sometimes even tortuous (Fig. 57).

Just before reaching the temporal wall of the lacrymal sac the two canaliculi may, and as a rule do, join together and form one larger collective tube (Fig. 58). The length of this tube varies materially in different individuals, and it may be so short that it can hardly be recognized as a separate part. In other cases the two canaliculi reach and enter the lacrymal sac separately and ununited.

From their beginning at the lacrymal puncta to their entrance into the lacrymal sac the canaliculi are formed by a membrana propria, the connective tissue of which is largely intermingled with elastic elements. This membrana propria is lined with lamellated polygonal pavement epithelium (Fig. 59) which often forms a dozen or even more layers, seldom fewer than ten.

By means of these canaliculi, as stated, the tear-fluid is drained from the conjunctival sac into the larger receptacle, the lacrymal sac, and again from this into the nose by means of the nasal lacrymal duct.

The lacrymal sac (Fig. 60), lies in the fossa lacrymalis formed by the lacrymal bone and the frontal process of the supramaxillary bone, and between the branches of the internal palpebral ligament. It forms a comparatively narrow, almost slit-like, cavity, which has a great many diverticles and folds. Its epithelium consists of a basal layer of more cuboid cells and of an inner layer of cylindrical cells. I have never seen ciliated cells (Figs. 59, 61).

The material of lacrymal sacs which I have been able to obtain for microscopical study has been rather limited and I have seldom had an entire lacrymal sac for examination. Usually it was only the upper and temporal part. I therefore cannot give from my own knowledge a more detailed description of its structure and will refer only to one point of interest, which, more especially, belongs to this paper, dealing, as it is, with the glandular organs belonging to the eyeball and its appendages.

It has been, and still is, a moot question, whether or not true glandular tissue is found in the walls of the lacrymal sac. From my specimens I cannot see how the existence of such glandular tissue can be doubted. As to the character of the glands and their secretion we can only speculate by comparison with other glands. I find usually two forms of glands and both of these often in considerable numbers, especially in the wall opposite the entrance of the collecting tube of the canaliculi.

The one kind is of the acinous type and corresponds in its structure exactly with the acinous glands found in the eyelids, conjunctiva and caruncle (Figs. 62 to 66). The structure of the other kind is more that of tubular glands, like the sudoriferous glands (Figs. 67, 68.)

I have never had an occasion to examine the structure of the nasal lacrymal duct.

REMARKS ON THE LITERATURE CONCERNING THE SUBJECTS OF THIS PAPER.

In how far, what I have found and described in the foregoing pages corresponds with or disagrees with what other investigators on this subject have found and laid down in literature, may be judged from the following brief survey of the more important works on the subject from the literature at my disposal.

I started out more particularly on this investigation, because I could get no satisfactory explanation as to what glands were referred to by the different authors, when speaking of the "glands of Krause." As I could not procure Krause's own original description * I had to rely on what the text-books could give me, and this is what I found.

H. Frey † states that "in man we find small acinous glands, so-called *mucous* glands (according to Henle '*accessory lacrymal* glands'). They lie in the fornix of the conjunctiva between the tarsal tissue and the eyeball, and there are in the upper eyelid as many as 42 of them, in the lower eyelid from 2 to 6."

What Frey here refers to, are probably the lacrymal glands forming the palpebral or inferior lacrymal gland and the adjoining separate lobules which I have described, and which together may number about 40. Why, however, he calls them *mucous* glands, Frey does not explain.

W. Waldeyer ‡ says: "The *acino-tubular* glands in man lie in certain distinct localities, at the edge of the tarsus nearest the fornix, and *with preference in its nasal part.* There they are found, partially along the edge of the tarsus, and partially within the tissue of the tarsus itself. They are more numerous in the upper eyelid than in the lower one; according to *Krause and his pupil Kleinschmidt* there are about 42 of them in the upper and from 6 to 8 in the lower eyelid. Their excretory ducts open into the conjunctiva of the fornix. The glandular body belonging to an excretory duct is relatively large and consists of short tubular glandular chambers to which round acini are attached in large numbers." Yet, in the text to his beautiful illustration, he calls the acinous glands lying buried *wholly within the tarsal tissue itself, the acino-tubular glands.*

Surely it is utterly impossible from these two apparently authoritative descriptions to arrive at a clear and distinct idea of what is meant by the term "Krause's glands." Frey calls them mucous glands or, with Henle, accessory lacrymal glands, and Waldeyer states that they lie with preference in

* Zeitschrift für rationelle Medicin. **4**: 337. (1854).

† Handbuch der Histologie and Histochemie des Menschen. 673. Leipzig. 1874.

‡ Handbuch der gesammten Augenheilkunde, von A. Graefe u. Th. Saemisch. 1[1]: 238. Leipzig. 1874.

the *nasal* side of the eyelid and calls them *acino-tubular* glands. Yet, both of these authors agree in stating that they found 42 such glands in the upper eyelid, and but slightly differ as to the minimum number in the lower eyelid, while they again agree as regards their maximum number.

In my description I have, therefore, refrained from using this term for any of the glands which I have found. I may, however, state that the idea of most authors seems to be that the glands which are found in the conjunctiva of the nasal part of the upper eyelid are "Krause's glands." That the number of these glands is very small and never comes near being 42, has been seen from my description. That number can only refer to the palpebral lacrymal glands.

E. Fuchs * says: "Upon the fornix, especially in its *nasal half*, lie the acinous glands of Krause, while *in the temporal half of the tarsus* are found lobules similar in character but more densely packed, representing *the inferior lacrymal gland*." This may, perhaps, sound differently in the original. Certain it is, that the inferior or palpebral lacrymal gland does *not lie in the tarsus.*

On page 560 of the same text-book, Fuchs makes the statement (translation) that the *inferior* lacrymal gland consists *of only one or two lobules*, for which reason it is also known as the accessory lacrymal gland.

It does not seem possible that by these two statements he refers to one and the same glandular structure.

A good description, both of the orbital and of the inferior lacrymal gland, is given by E. Bock in a monograph on the lacrymal gland in health and disease.†

The best, most extensive and most careful researches and descriptions, and those which most nearly correspond with what I have found, were made by A. Terson, whose excellent monograph ‡ has come to my knowledge and into my posses-

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* Text-book of Ophthalmology. Translated by A. Duane. 2d American edition. New York. 1899. In the text beneath *Fig. 164* (p. 561).

† Zur Kenntniss der gesunden und kranken Thraenendruese. Wien. 1896.

‡ Les glandes lacrymales conjonctivales et orbito-palpébrales. L'ablation des glandes lacrymales palpébrales. Paris. 1892.

sion only when my investigations on this subject were, so to speak, closed.

For macroscopic inspection Terson clears the whole eyelids up, by means of tartaric or acetic acid. He says: "In the outer third of the specimen the palpebral lacrymal gland with *its own excretory ducts* and those of the orbital lacrymal gland is plainly seen." Further on: "It is not difficult to recognize a long line of very much smaller glands, forming, as Mr. Panas has so happily expressed it, a sort of 'milky way' in the upper conjunctival cul-de-sac. Of these glands there is a continuous row, and they grow gradually larger towards the inner angle."

Further on, he says: "In the lower cul-de-sac I find a few glands very similar to those in the upper one, but they do not reach the inner angle and are situated in that half of the lower eyelid which lies close to the palpebral lacrymal gland."

In these particulars Terson's description varies but little from my own.

His description of the acino-tubular glands in the tarsal tissue, also, agrees very well with mine. His experience has, also, been that these glands are found most frequently in the *temporal* half of the tarsal tissue, but often, too, in the nasal or other parts. Contrary to my experience, he finds their excretory ducts to be very long and very tortuous. He also has found, that their duct may pass down, in between the Meibomian glands. He further states that the epithelium of these glands as well as that of their excretory ducts appears identical with that of the acinous glands of the fornix, and that the external orifices of the excretory ducts of the acino-tubular glands lie in the conjunctiva of the *upper* cul-de-sac or at other points of the tarsus and often even very near the lidmargin.

From this it would appear, that he never found such acino-tubular glands in the *lower* eyelid.

With regard to the glands found in the walls of the lacrymal sac, a very exhaustive paper by K. Joerss has appeared as No. 35 of Deutschmann's Beitraege zur Augenheilkunde, Leipzig, October 29th, 1898. (Beitraege zur normalen and pathologischen Histologie des Thraenenschlauches). Joerss made his studies on excised lacrymal sacs, and one of his objects was to see, whether *true glands* could be found in the lacrymal sac, or not. In consequence, he devotes considerable space to this question and his conclusion is that, contrary to the statements of other investigators, true glands are really sometimes found lying in the normal mucous membrane of the lacrymal sac; but, according to his investigation, they are *serous glands, of the type of Krause's glands of the conjunctiva.* Mucous glands, according to him, have, thus far, been found with certainty only at the orifice of the nasal lacrymal duct in the nose, and it is still a moot question, whether these mucous glands belong in reality to the nasal lacrymal duct or to the mucous membrane of the nose. This investigator has, therefore, seen only one form of glandular tissue lying in the walls of the lacrymal sac, namely the acinous form, which seems to be the most frequent one of the two forms which I have found and described.

It is a strange fact, that aside from Waldeyer's article in Graefe & Saemisch's Cyclopaedia, mentioned above, and its translation into French in De Wecker's Traité complet d'ophtalmologie, and of the parts referring to the eyelids and lacrymal apparatus in Fuchs' text-book, the text-books on ophthalmology in general deal but very insufficiently with the glandular structures which are the subject of these investigations. Especially, in the first volume of the large, very recent, and generally admirable system of diseases of the eye, published by Norris & Oliver, Philadelphia, 1897, in the able article on the anatomy of the orbit and the appendages of the eye by T. Dwight, these points, it seems to me, are passed over too lightly. The lacrymal caruncle, for instance, though not a very important organ, might have received a little more attention than is expressed in the following words: "A raised pinkish little body, the lacrymal caruncle (Vol. I, p. 80)." The largest amount of the literature on the subjects here considered, is dispersed in journals and magazines which are not, as a rule, even ophthalmological ones, and it is, therefore, not easily obtained.

With regard to the small portion of hyaline cartilage tissue which in one instance I found just below the lacrymal caruncle, I have detected only one statement in literature of a somewhat similar occurrence. In the text-book of A. Boehm and M. von Davidoff * the following statement is made (p. 349): "The third eyelid, the plica semilunaris, when well developed, contains a small spicule of hyaline cartilage."

In illustrating the details of their descriptions of the eyelids, most text-books give a longitudinal (sagittal) section through the thickness of the upper lid near the temporal canthus. From the descriptions here given, it is clear that one such drawing (not even excluding Waldeyer's often copied and classical one) cannot be sufficient, as the details of the tissues of the eyelids differ so very materially in their different portions (Figs. 69 to 71).

EXPLANATION OF ILLUSTRATIONS.

Plates XXII–LVII.

Plate XXII. — 1, Vertical (sagittal) section through the orbital lacrymal gland (A) and the more compact portion of the inferior or palpebral lacrymal gland (B), from a negro. — 2, Vertical (sagittal) section through the temporal outer third of the upper eyelid and the eyeball, from a white individual, showing the orbital and part of the palpebral lacrymal gland. — 3, Section the same as in Fig. 2, from a negro. The magnifying power under which the last two photographs were taken being the same, the great difference in size of the two orbital lacrymal glands is evident.

Plate XXIII. — 4, From a negro. Section the same as in Figs. 2 and 3, but still further toward the temporal canthus, showing a large number of lobules belonging to the palpebral lacrymal gland.

Plate XXIV. — 5, Part of the palpebral lacrymal gland of Fig. 2 under a higher magnifying power. Above, part of the orbital lacrymal gland; to the left, the orbicularis muscle; to the right, the conjunctiva, sclerotic and choroid. The palpebral gland is seen to be separated from the orbital one by the tendon of the levator palpebrae superioris and the nonstriated muscle of Mueller. — 6, Vertical (sagittal) section through both eyelids at the temporal canthus, showing lobules of the palpebral lacrymal gland in the lower eyelid as well as in the upper one, from a negro.

Plate XXV. — 7, Vertical (sagittal) section through the lower eyelid near the temporal canthus (white), showing a Meibomian gland (A), below it acino-tubular glands (B), and below these, three lobules of the lower

* Lehrbuch der Histologie des Menschen, einschliesslich der mikroskopischen Technik. Wiesbaden. 1898.

palpebral lacrymal gland with an excretory duct between them. To the left the orbicularis muscle. — 8, Vertical (sagittal) section through the upper eyelid and eyeball (white), just through the middle line. The small round dark body in the subconjunctival tissue above the tarsus (→) is an isolated small lacrymal gland.

Plate XXVI. — 9, The same lacrymal glands as in Fig. 8, under a high magnifying power. — 10, Three lobules of the palpebral lacrymal gland in the upper eyelid, and an excretory duct.

Plate XXVII. — 11, The distal end and external orifice of one of the excretory ducts of the orbital lacrymal gland (vertical section). — 12, Several lobules of the palpebral lacrymal gland of the upper eyelid; upwards an excretory duct from the orbital lacrymal gland. The epithelium of the conjunctiva has fallen off.

Plate XXVIII. — 13, Vertical section through two lobules of the palpebral gland, one with its excretory duct, upper eyelid. — 14, A large lobule of the palpebral lacrymal gland with its excretory duct, upper eyelid.

Plate XXIX. — 15, A large lobule of the palpebral lacrymal gland with its excretory duct. To the right of it a transverse section of an excretory duct from the orbital lacrymal gland. The conjunctival epithelium has fallen off. — 16, The external orifice of the excretory duct of a small isolated lacrymal gland in the conjunctiva. Lymphatic infiltration around and near it. To the left the bulbar conjunctiva. The epithelium has fallen off.

Plate XXX. — 17, Small acinous gland in the upper eyelid close to the nasal canthus (→). Vertical section through upper eyelid and eyeball. The lacrymal caruncle is seen below. — 18, The same gland under a higher magnifying power.

Plate XXXI. — 19, 20, Acinous glands from the conjunctiva near the lacrymal caruncle, upper eyelid.

Plate XXXII. — 21, Horizontal section through the lower eyelid a little below the caruncle. An acinous gland imbedded in the loose connective tissue. Upwards to the left side the conjunctival sac. — 22, A part of the same gland and its duct under a higher magnifying power.

Plate XXXIII. — 23, Horizontal section through the eyelids showing the tarsal tissue, including some Meibomian glands, some acino-tubular glands in the middle line, and small acinous glands in the conjunctiva at both the temporal and nasal edges of the tarsus (A, B). — 24, The same. The skin and orbicular muscle torn off.

Plate XXXIV. — 25, Similar section to Figs. 23 and 24. — The dark lines in the conjunctiva represent the lymphatic infiltration. — 26, Somewhat oblique vertical section through the upper eyelid, showing the lower part of a Meibomian gland and its excretory duct. To the right of it appears to be a second layer of glandular tissue; this is, however, only apparent and due to the obliqueness of the section. To the right of the excretory duct lies the muscle of Riolan and the dark root of an eyelash (negro).

Plate XXXV. — 27, Vertical section through the tarsal tissue and Meibomian glands parallel to the surface, from the lower eyelid, close to the conjunctival surface. — 29, Section parallel to the surface through the temporal third of the upper eyelid, showing Meibomian glands with dilated central ducts, and above them the acino-tubular gland as dark patches.

Plate XXXVI. — 28, Similar section to that shown in Fig. 27.

Plate XXXVII. — 30, The same section as shown in Fig. 29, from the lower eyelid. Near the lidmargin in both of these figures a number of dilated modified sweat-glands appear as small white spots. — 31, Horizontal section from near the upper edge of the tarsus of the upper eyelid, showing the acino-tubular glands in the temporal side; also, a small acinous gland in the conjunctiva. Below is seen the bulbar conjunctiva.

Plate XXXVIII. — 32, Horizontal section through the tarsus of the upper eyelid just above the nasal canthus. There are a number of transverse sections of Meibomian glands and a large compact body of acino-tubular glands in the nasal part of the tarsus (A). — 33, Horizontal section through the central part of the upper eyelid. In the middle line acino-tubular glands are seen lying between the Meibomian glands at A.

Plate XXXIX. — 34, Section the same as in Fig. 33, but nearer the lidmargin. In the middle line, at A, a small piece of an acino-tubular gland with its excretory duct is seen; also, its external orifice in the palpebral conjunctiva. — 35, A similar section under a higher magnifying power. To the right and left side of the acino-tubular gland a Meibomian gland is seen.

Plate XL. — 36, Vertical section through the lower eyelid, near the temporal canthus. Downwards, the very much dilated central duct of a Meibomian gland; above it a number of acino-tubular glands, undergoing atrophy. The conjunctiva to the right shows changes due to chronic blennorrhoea. — 37, Acino-tubular gland from the upper eyelid under a high magnifying power. A great many acini are atrophied.

Plate XLI. — 38, Vertical section of the upper eyelid; high magnifying power. In the left lower corner the dilated apex of a Meibomian gland; above it lobules of an acino-tubular gland torn apart in mounting; also an excretory duct with its external orifice in the palpebral conjunctiva. The conjunctival epithelium has fallen off. — 39, A concretion in the excretory duct of an acino-tubular gland close to its external orifice in the palpebral conjunctiva, the epithelium of which has fallen off. This concretion was semi-soft and took up those stains with preference for which mucous substances have a special affinity.

Plate XLII. — 40, Two horizontal sections through the lidmargin. The upper one, from the upper eyelid, goes through the shafts of the eyelashes; the lower one, from the lower eyelid, goes through the bulbs of the eyelashes. Both sections show numerous transverse sections through Meibomian and modified sweat-glands, as light spots. — 41, Vertical (sagittal) section through the margin of the upper eyelid: A, Meibomian gland and its duct; B and E, eyelashes and their sebaceous glands; C, modified sweat-gland; at D, the collecting chamber and excretory duct which does not enter the sebaceous gland of an eyelash, but has a separate orifice at the lidmargin; at F, a part of another modified sweat-gland is seen.

Plate XLIII. — 42, Vertical (sagittal) section through the margin of the lower eyelid of a negro. To the left, the conjunctiva, tarsus and a Meibomian gland with its excretory duct below; to the right, the skin of the eyelid; downwards, an eyelash, and just above it a modified sweat-gland with its secretory duct, the external orifice of which lies in the duct of a sebaceous gland; above this the root of an eyelash and the orbicularis muscle. Between the lower end of the Meibomian gland and the sebaceous gland lies Riolan's muscle. — 43, Horizontal section through the lidmargin at the level of the roots of the eyelashes, showing numerous transverse sections of hair-bulbs and between them modified sweat-glands. Downwards the transverse sections of three Meibomian glands near their lower end. The fibres seen running parallel to the conjunctival surface above the Meibomian glands and those between the modified sweat-glands and the hair-bulbs are the fibres of Riolan's muscle.

Plate XLIV. — 44, 45, Vertical sections, parallel to the surface, through the lid margins of the upper and lower eyelid, showing the modified sweat-gland and (abnormally dilated), between, the roots and shafts of the eyelashes, under a high magnifying power.

Plate XLV. — 46, Section the same as in Figs. 44 and 45, showing at A, B and C modified sweat-glands under a high power, having an altogether tubular appearance; above them are some acini of a Meibomian gland. — 47, Horizontal section through the lacrymal caruncle of a negro, showing sebaceous glands, the transverse section of a hair (upwards) and an acinous gland at A.

Plate XLVI. — 48, Vertical section through a lacrymal caruncle having two acinous glands (A and B). The epithelium has fallen off. — 49, Horizontal section through the lacrymal caruncle. Acinous glands at A.

Plate XLVII. — 50, Similar section to that shown in Fig. 49. — 51, Small body of hyaline cartilage lying in the loose tissue (in one lid only) of the lower eyelid, just below the caruncle. Horizontal section. The conjunctival epithelium has fallen off.

Plate XLVIII. — 52, This cartilage under a high magnifying power. — 53, Vertical (sagittal) section through both eyelids passing through the vertical portion of the lacrymal canaliculus of the upper eyelid and its orifice in the lacrymal papilla. The oblique section through the horizontal portion of the canaliculus is seen in the lower eyelid. The canaliculus is filled with desquamated epithelium.

Plate XLIX. — 54, Horizontal section through the upper eyelid showing the horizontal portion of the lacrymal canaliculus. Below is the lacrymal caruncle. — 55, Section through the axis of the lacrymal papilla and the vertical portion of the lacrymal canaliculus, showing its narrowest part just inside of the lacrymal punctum, from where it widens out gradually to where it bends to form the horizontal portion.

Plate L. — 56, Section like the one in Fig. 55. To the left the horizontal diverticle of the lacrymal canaliculus projects into the tissue of the eyelid (temporally), to the right (nasally) the beginning of the horizontal portion. This section does not pass exactly through the axis of the vertical portion of the canaliculus. — 57, Horizontal section showing a tortuous lacrymal canaliculus.

Plate LI. — 58, Section through both eyelids and nasal canthus almost parallel to their surface. To the left and downwards, nasal part of the upper, to the right and upwards, nasal part of the lower eyelid; between these the lacrymal caruncle. At the right the horizontal portions of the two canaliculi are seen to join at a sharp angle. — 59, The entrance of the lacrymal canaliculus into the lacrymal sac. The canaliculus lies to the right and is seen to be lined with a thick pavement epithelium; the lacrymal sac to the left is lined with cylindrical epithelium.

Plate LII. — 60, Horizontal section through the right lower eyelid (A) and the tissue at the side of the nose. The lacrymal sac at B.

Plate LIII. — 61, the walls of the lacrymal sac, showing the cylindrical epithelium and lymphatic infiltration, under a high magnifying power. — 62, Acinous glands in the wall of the lacrymal sac at A.

Plate LIV. — 63, Similar section to Fig. 62. — 64, Acinous gland of the lacrymal sac. The sac begins to the right downwards; the gland seems to lie some distance from it.

Plate LV. — 65, Another such acinous gland, with an oblique section through its excretory duct. — 66, Several acini of such a gland from the wall of a lacrymal sac, under a high magnifying power.

Plate LVI. — 67, 68, Glands in the wall of a lacrymal sac which have a more tubular structure.

Plate LVII. — 69, Schematic section through both eyelids and eyeball near the nasal canthus. — 70, Schematic section through the middle line of both eyelids and eyeball. — 71, Schematic section through both eyelids and eyeball near the temporal canthus.

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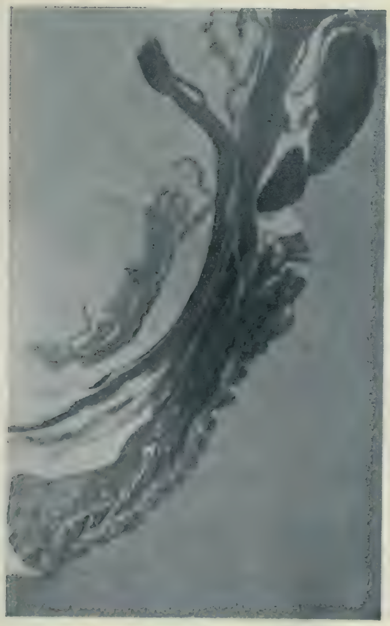

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GLANDS APPERTAINING TO HUMAN EYE.

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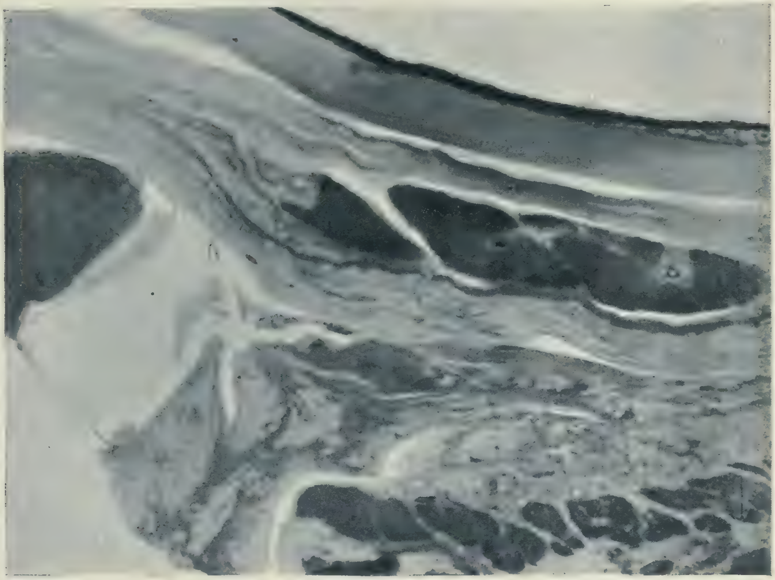

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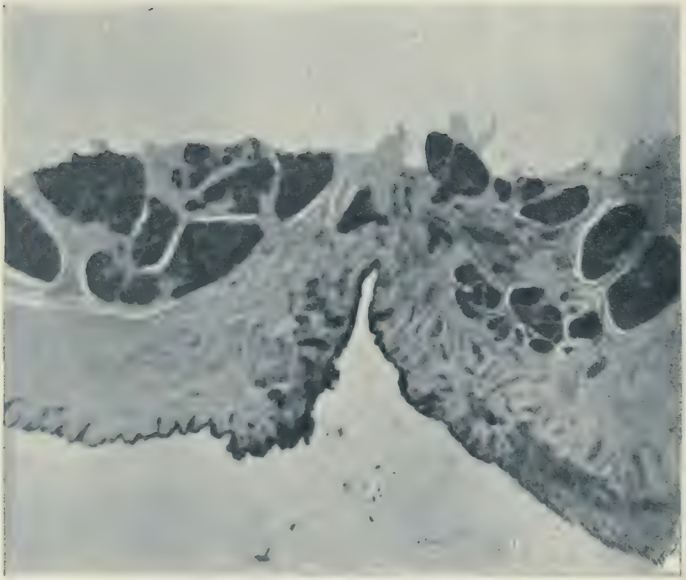

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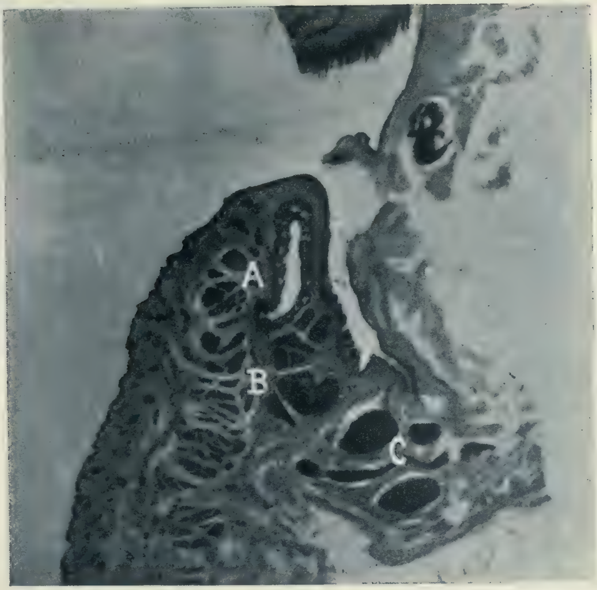

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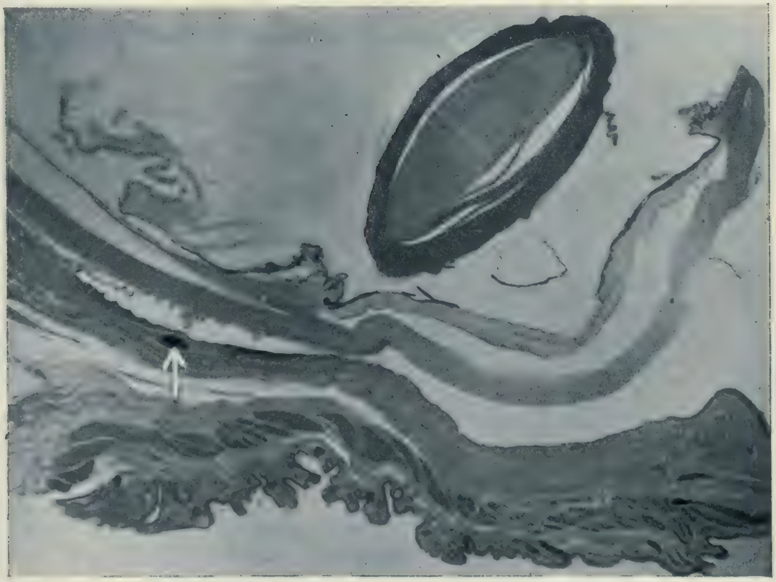

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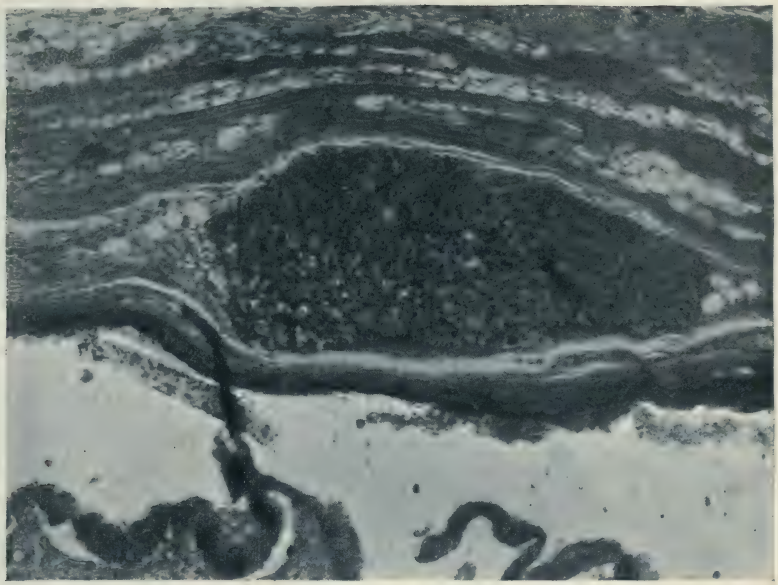

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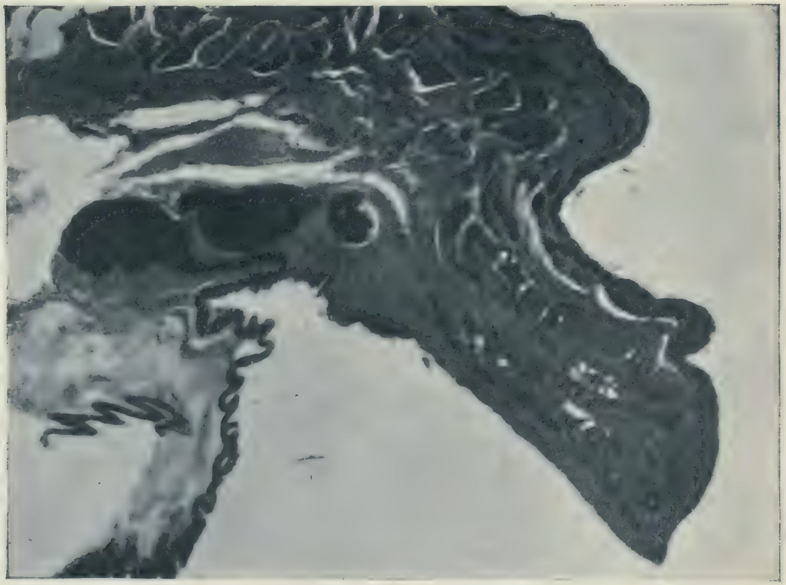

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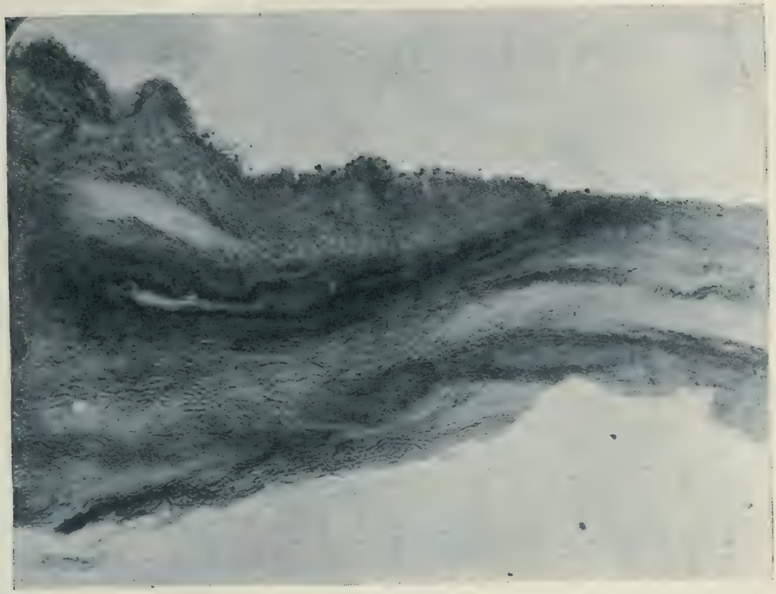

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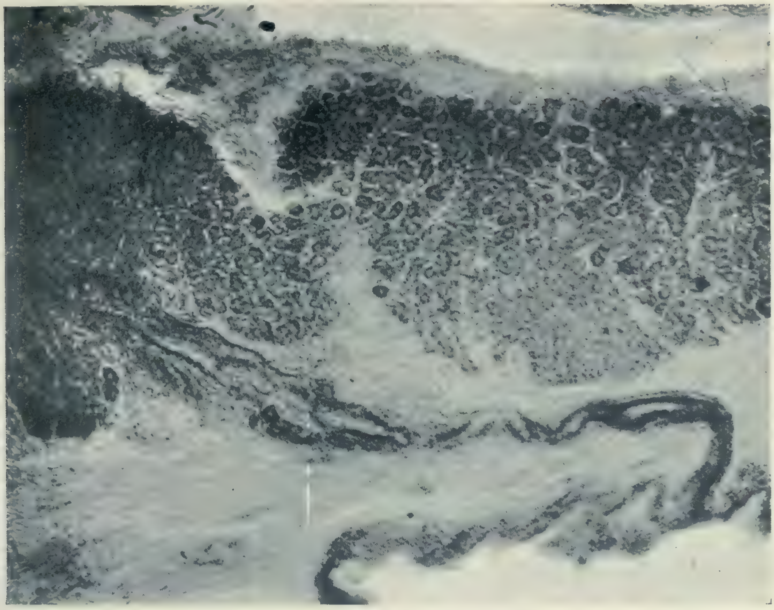

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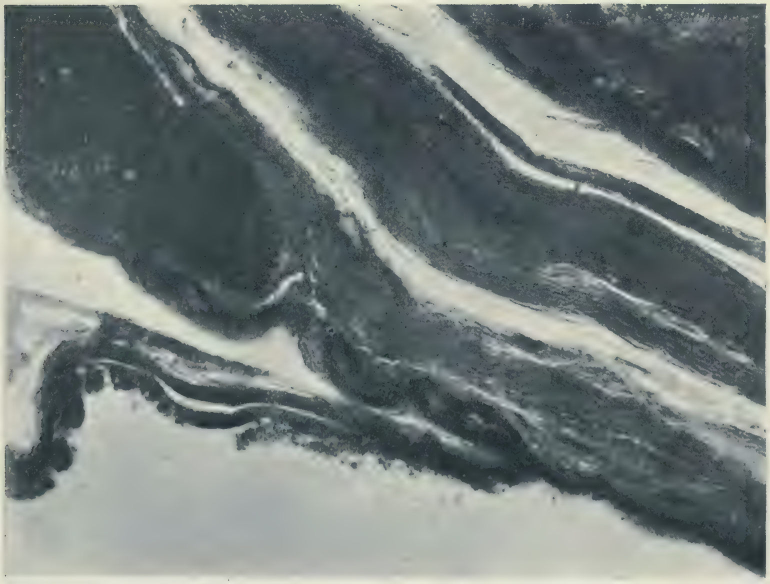

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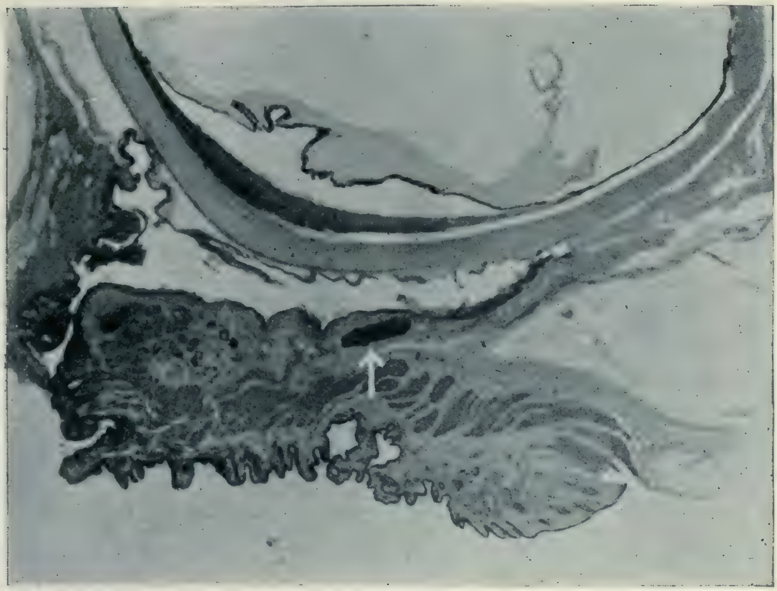

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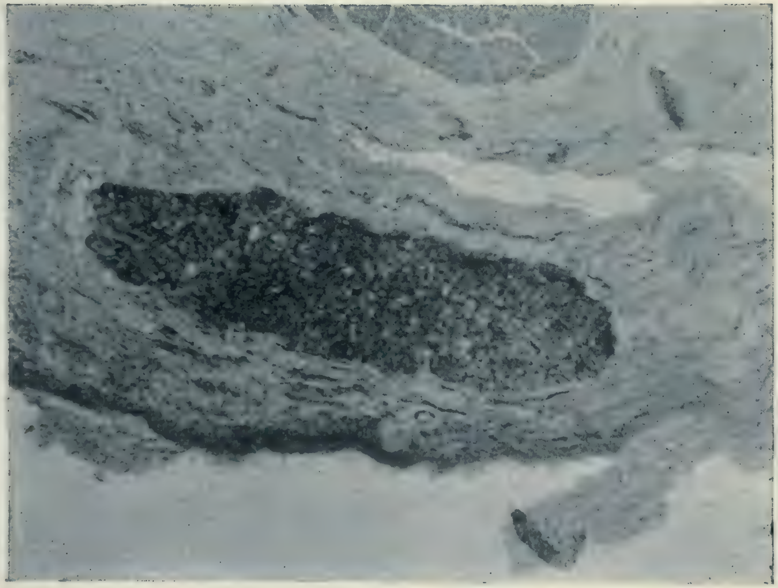

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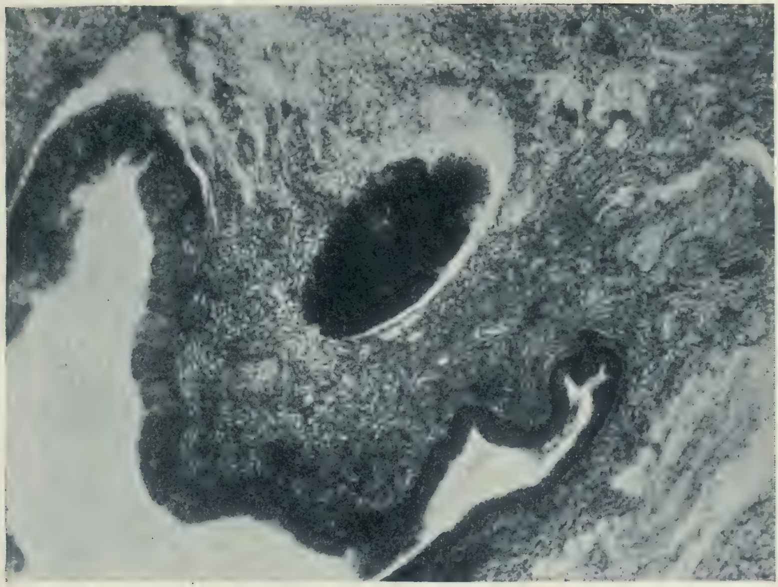

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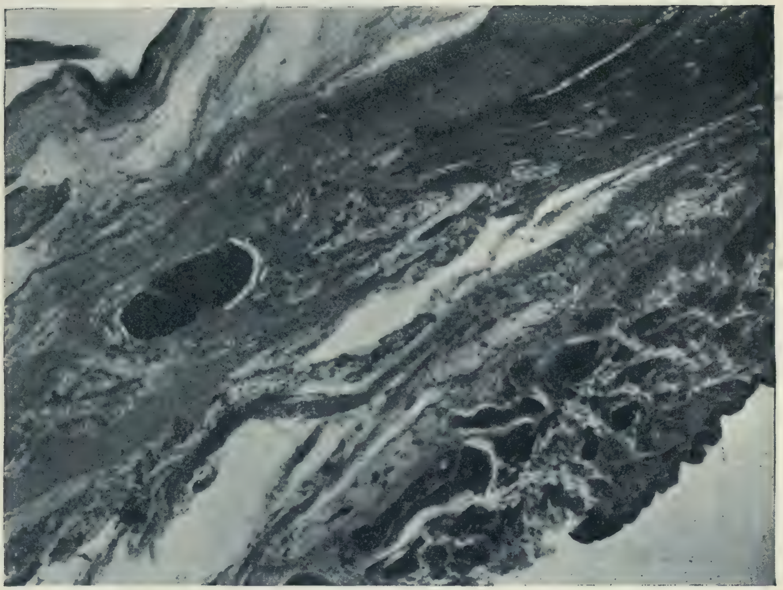

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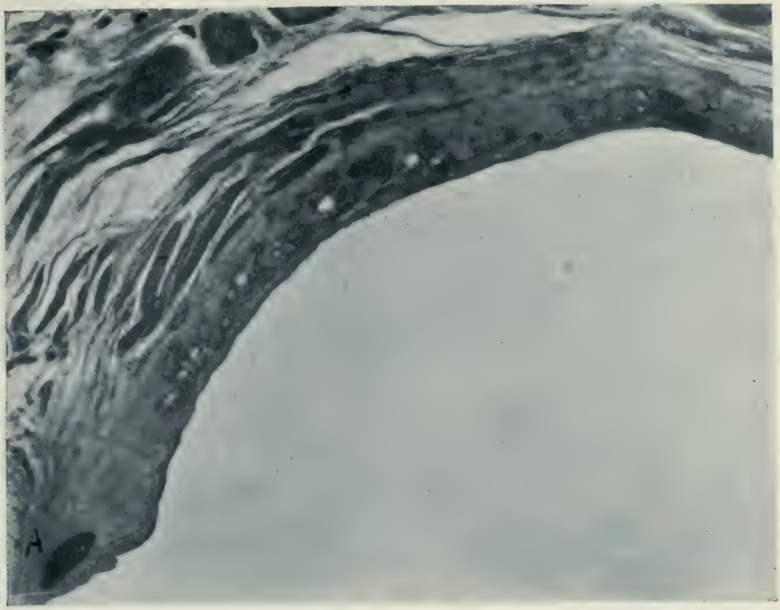

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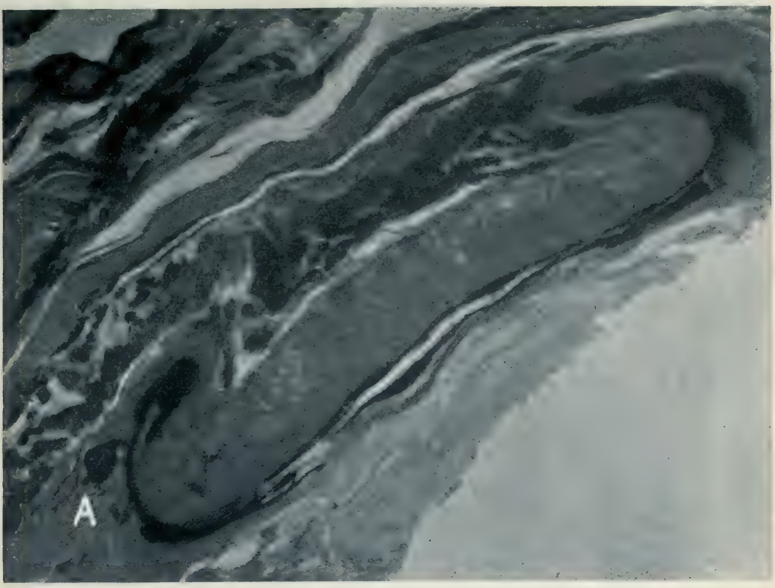

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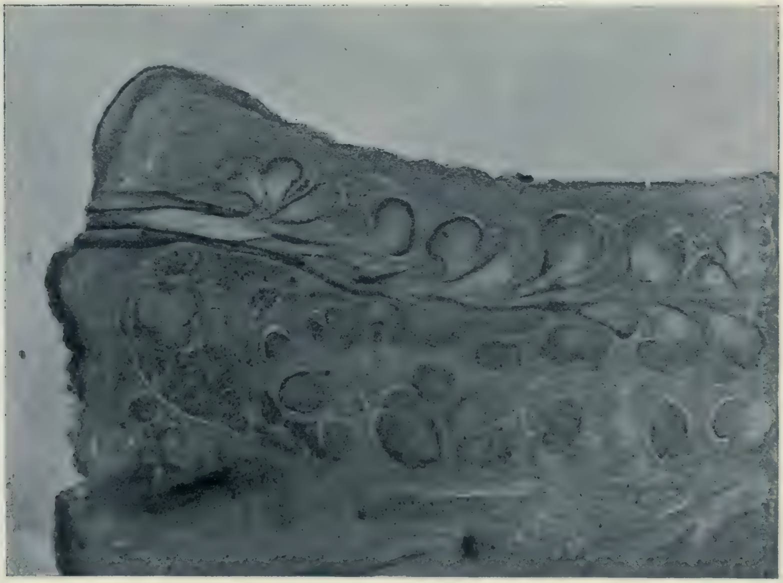

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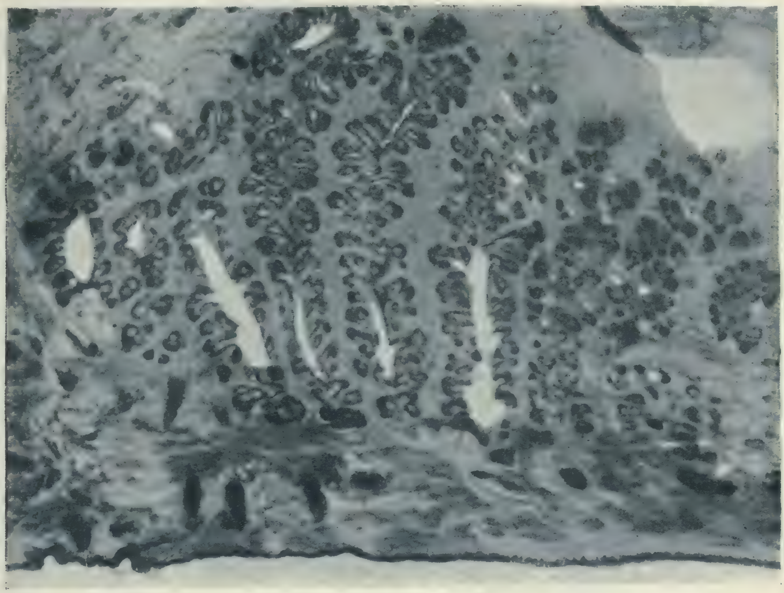

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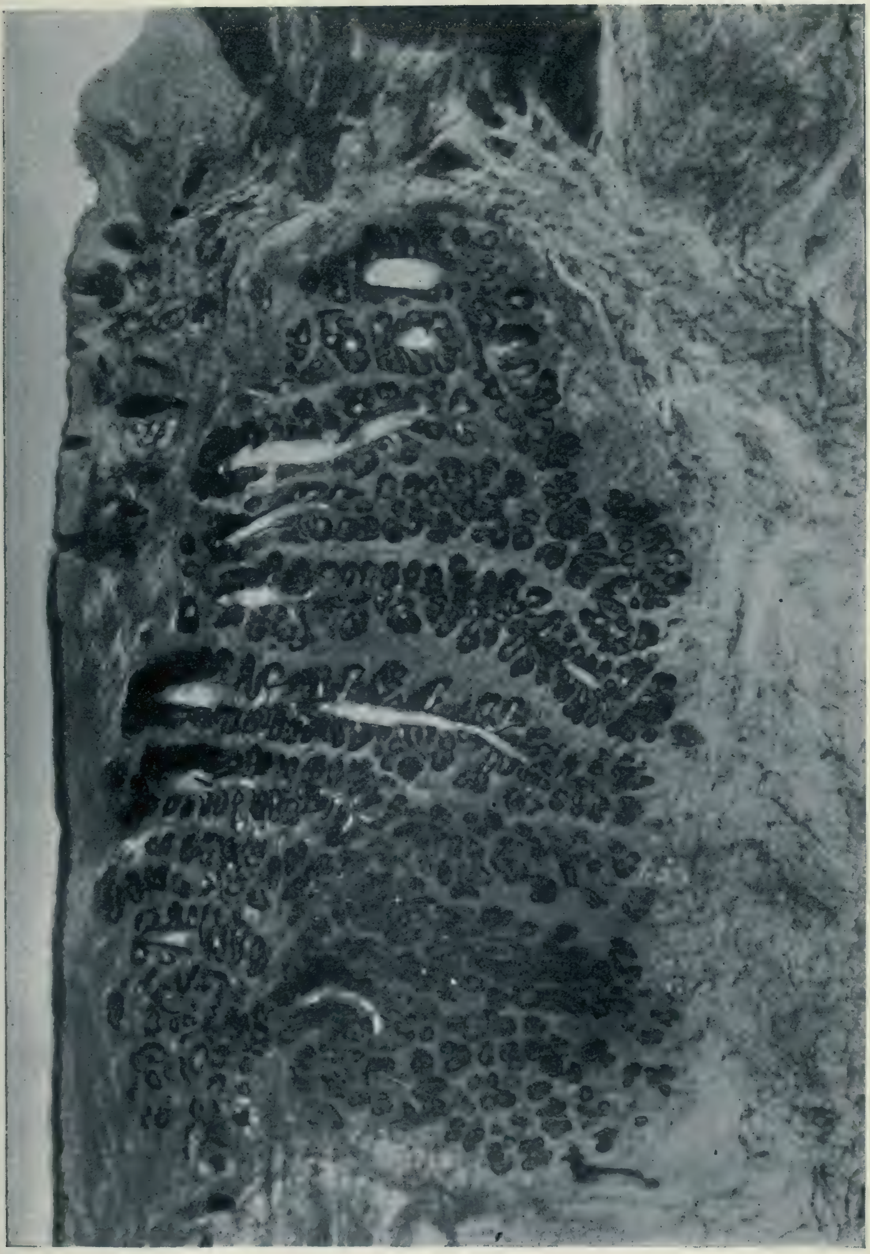

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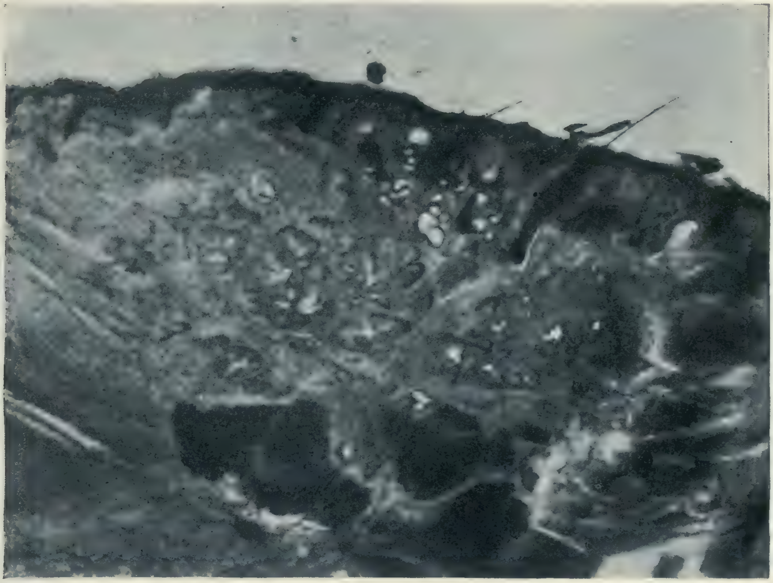

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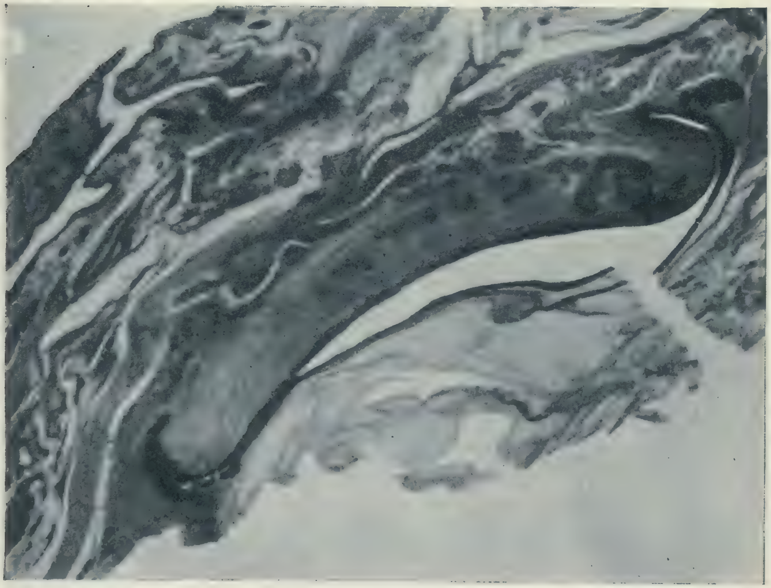

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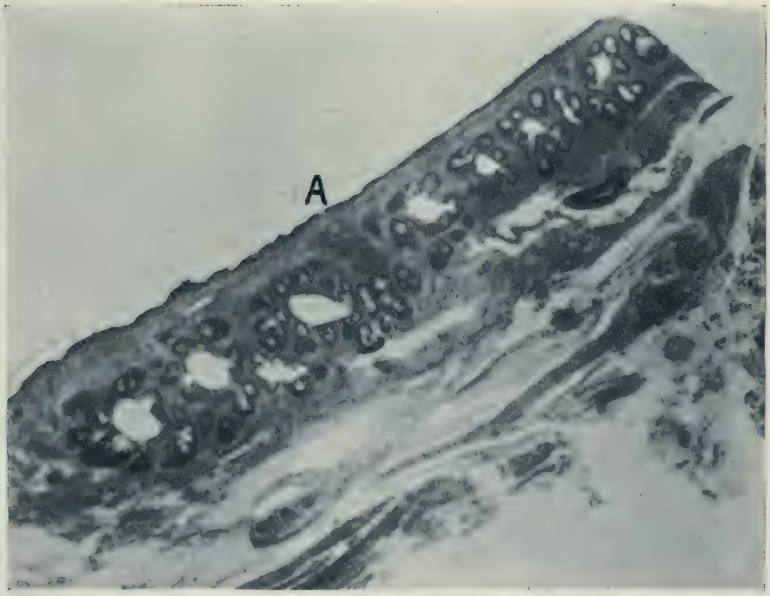

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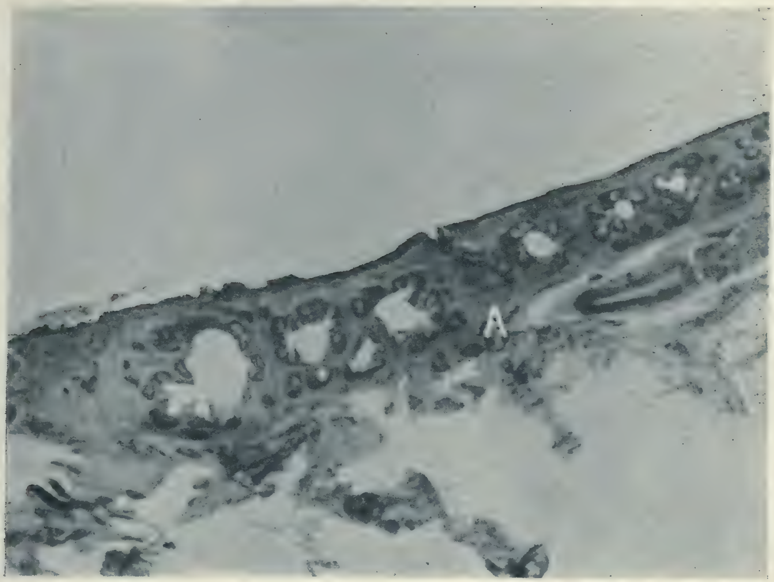

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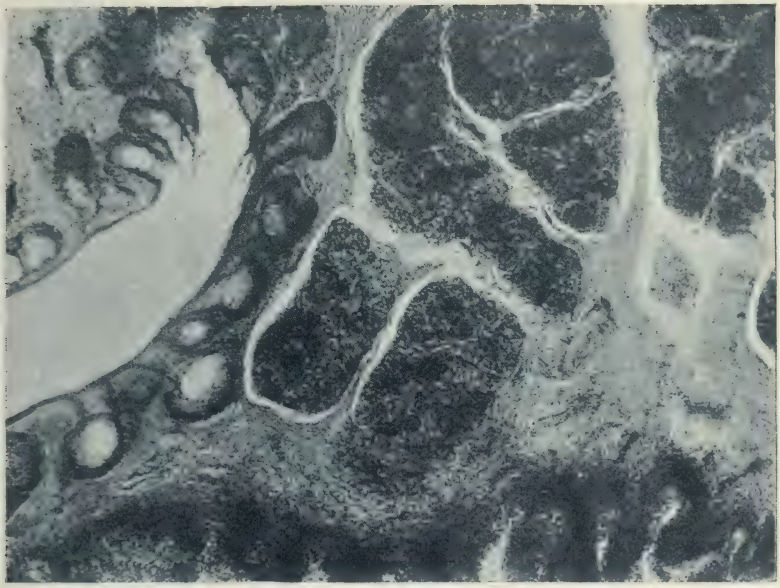

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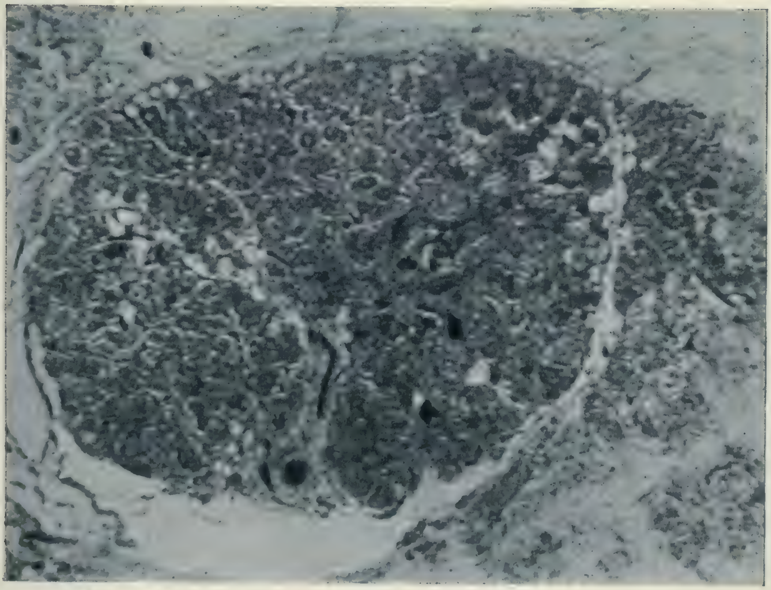

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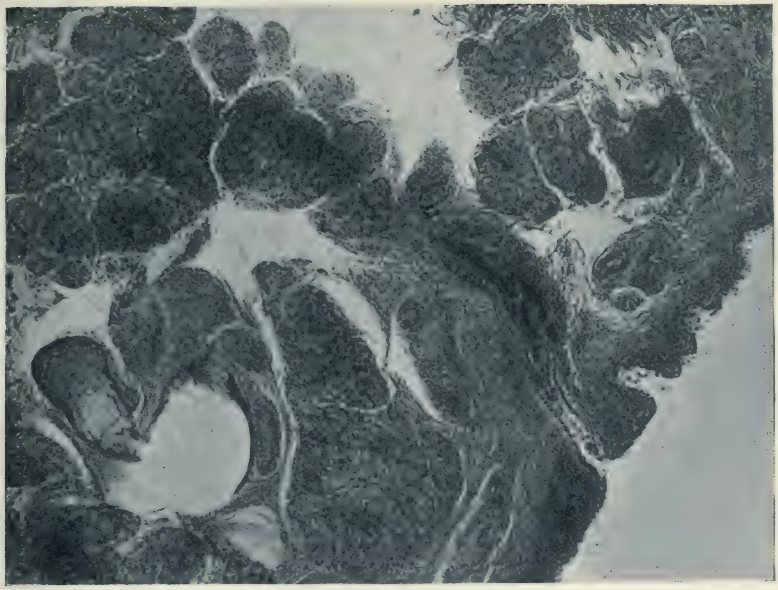

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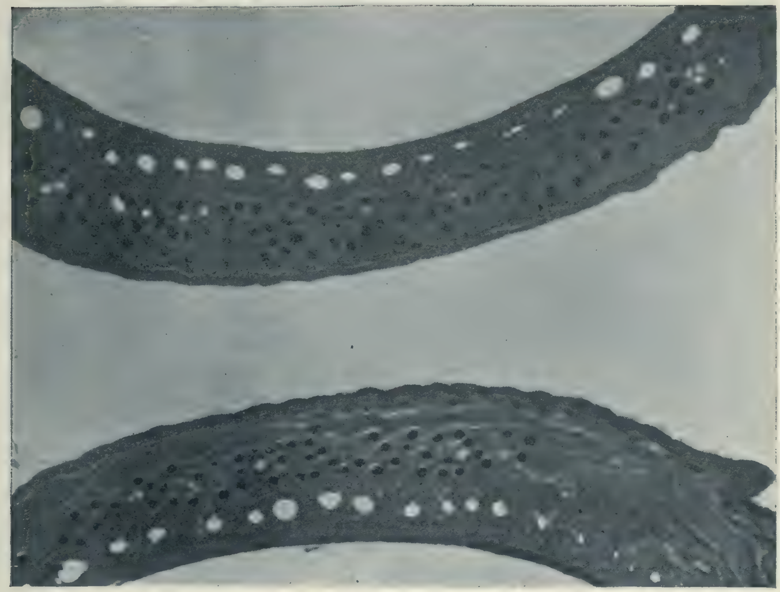

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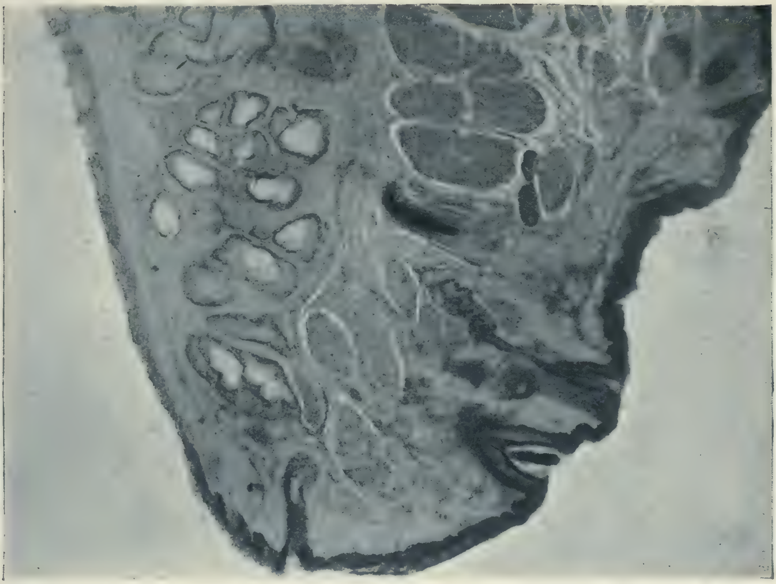

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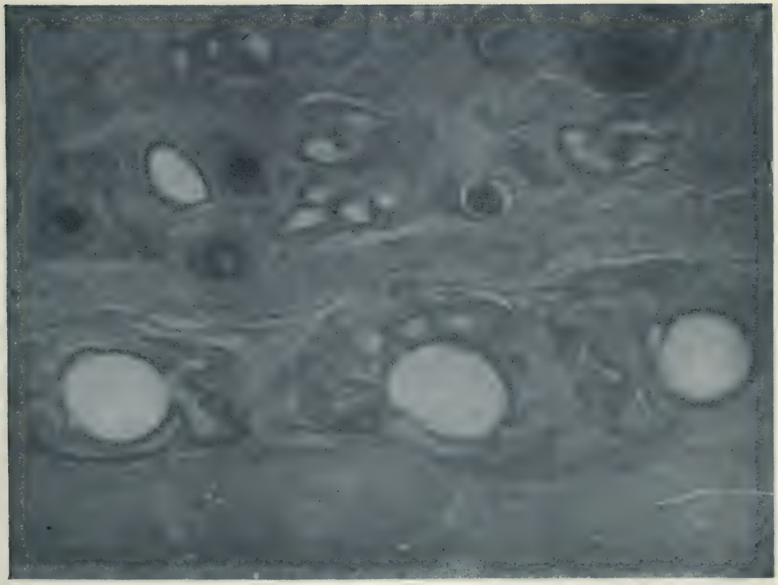

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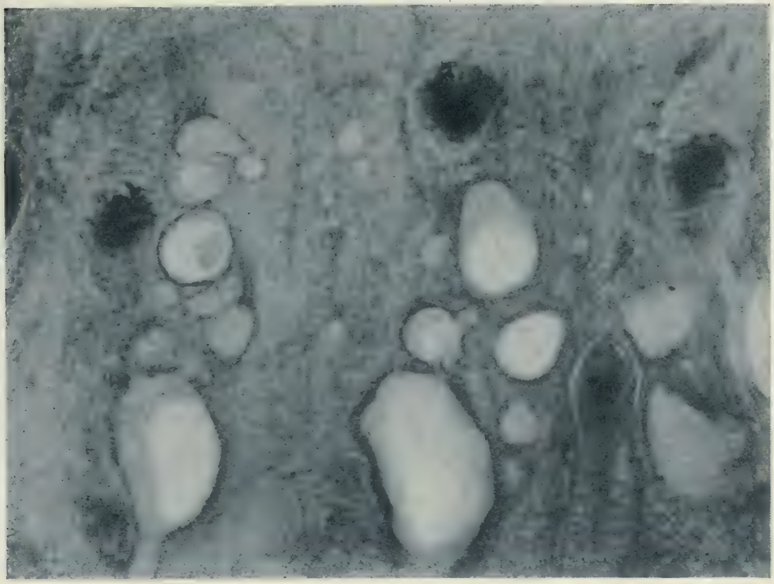

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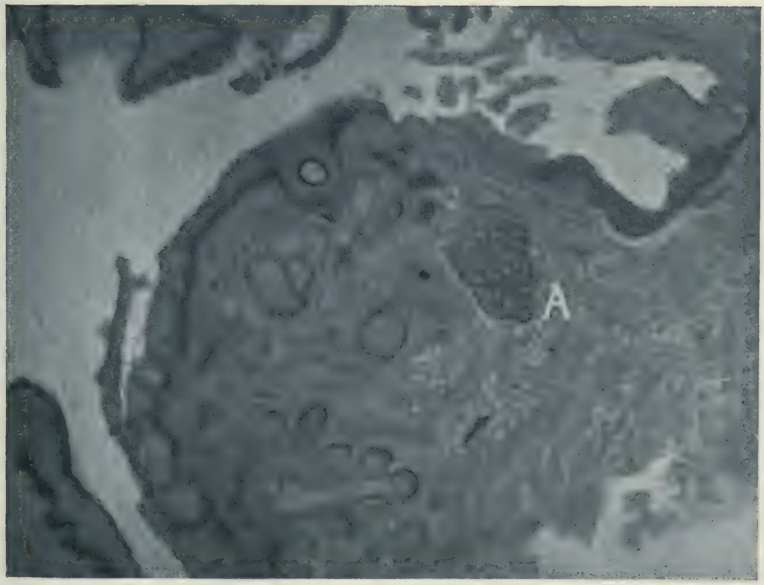

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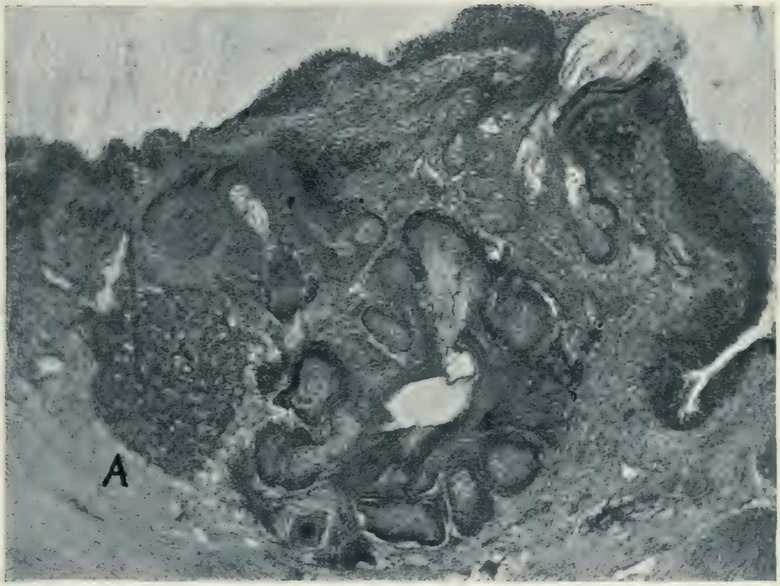

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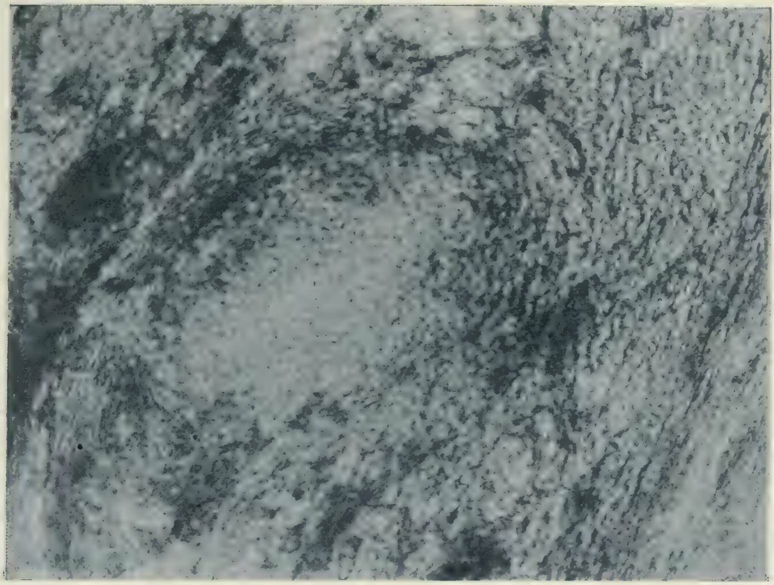

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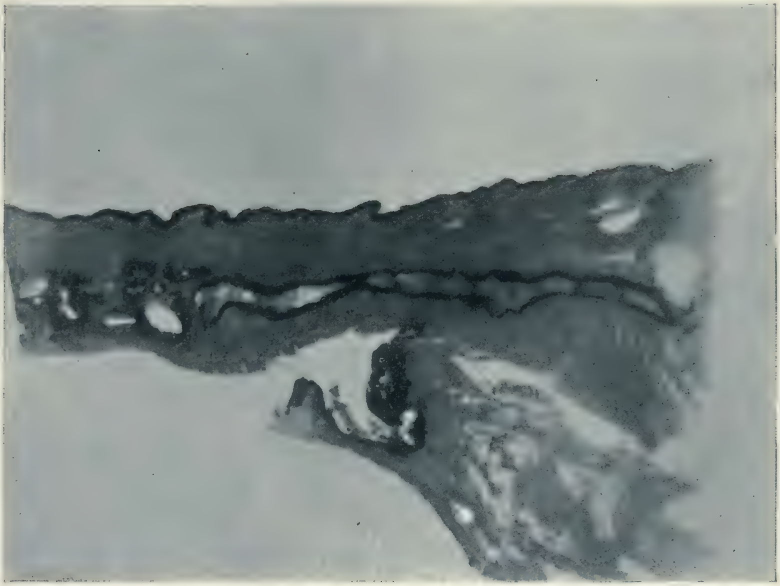

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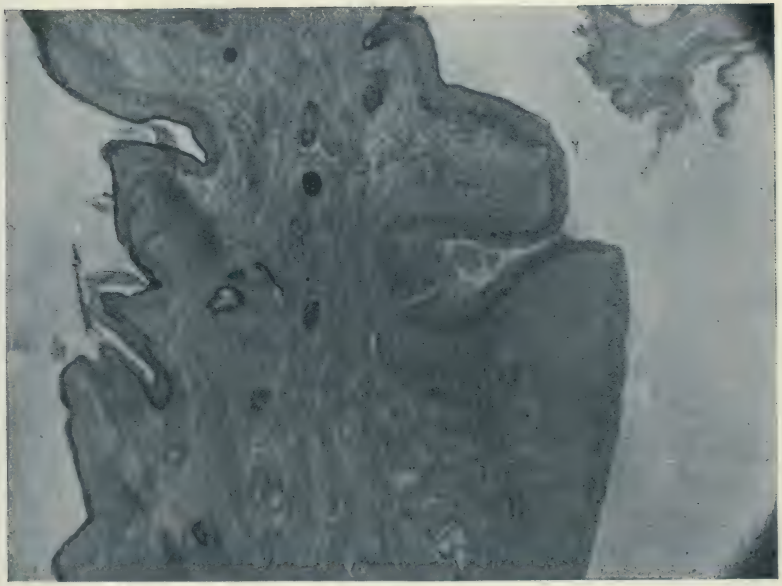

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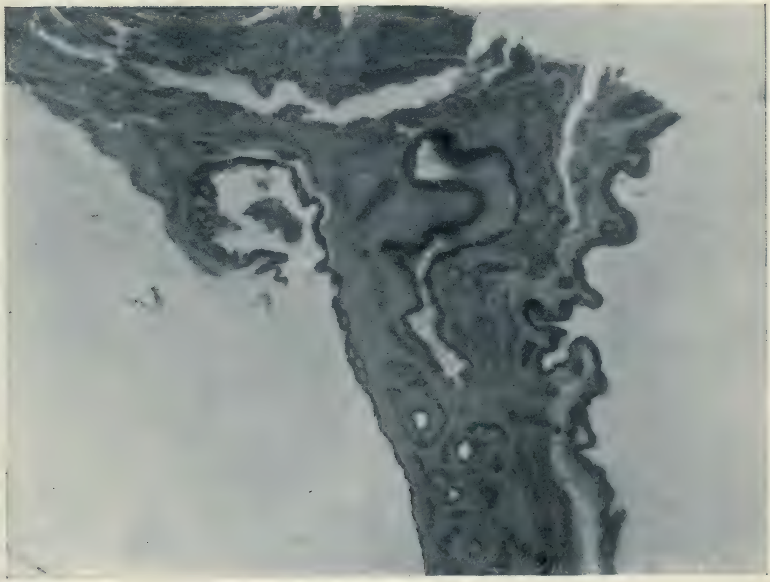

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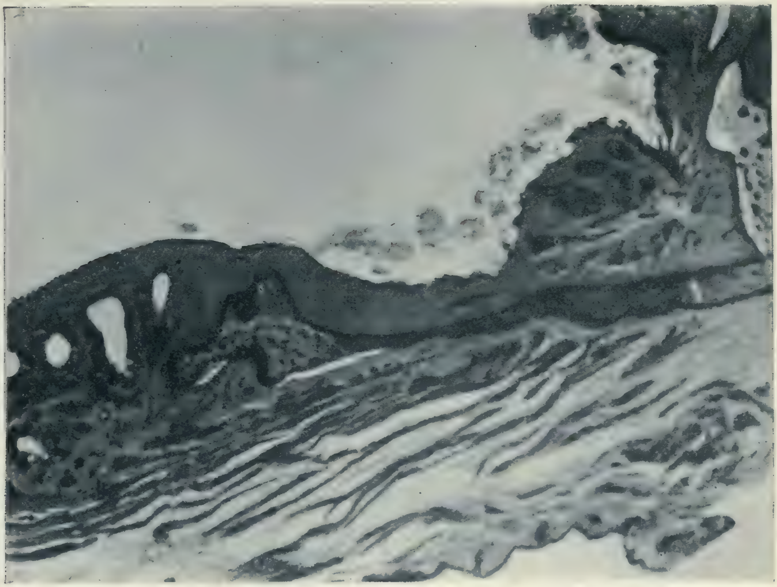

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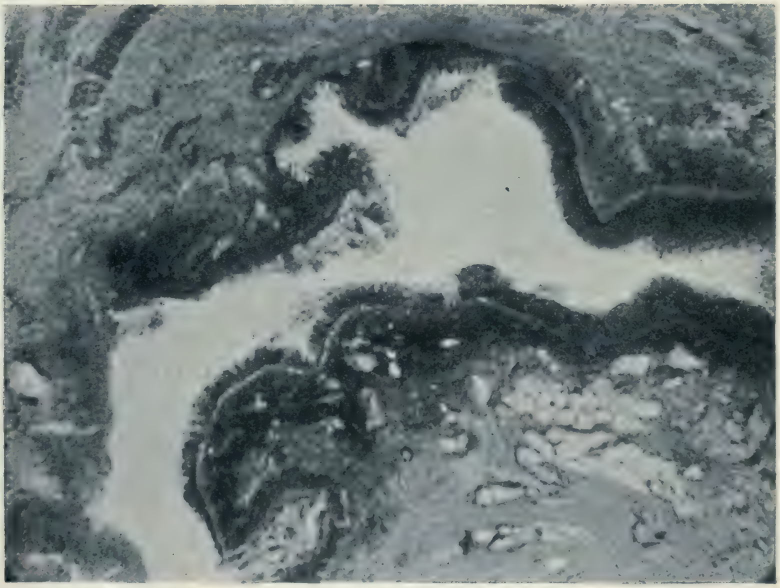

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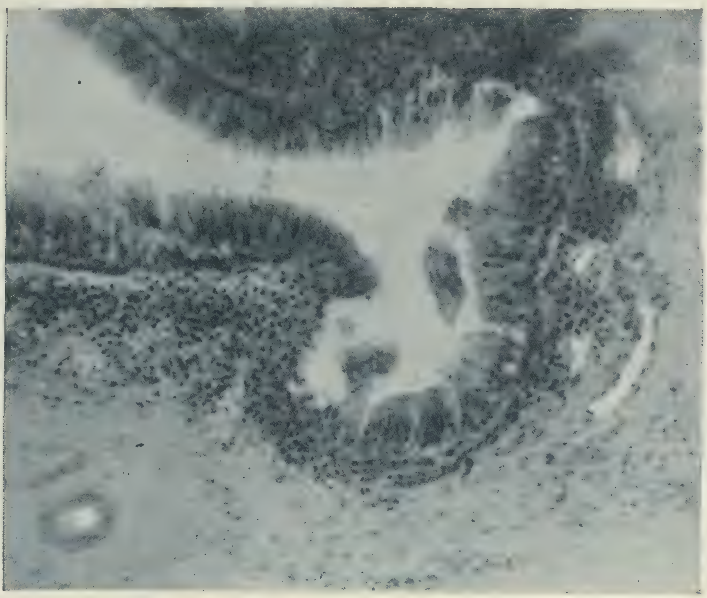

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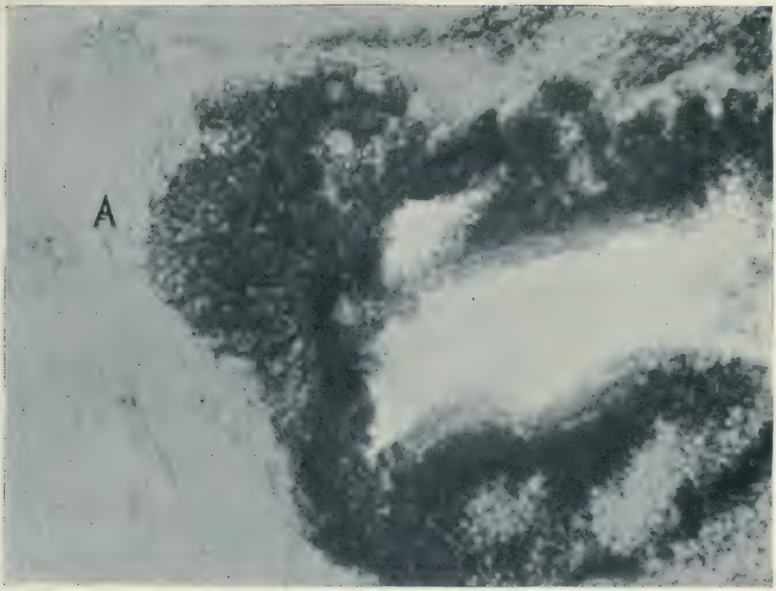

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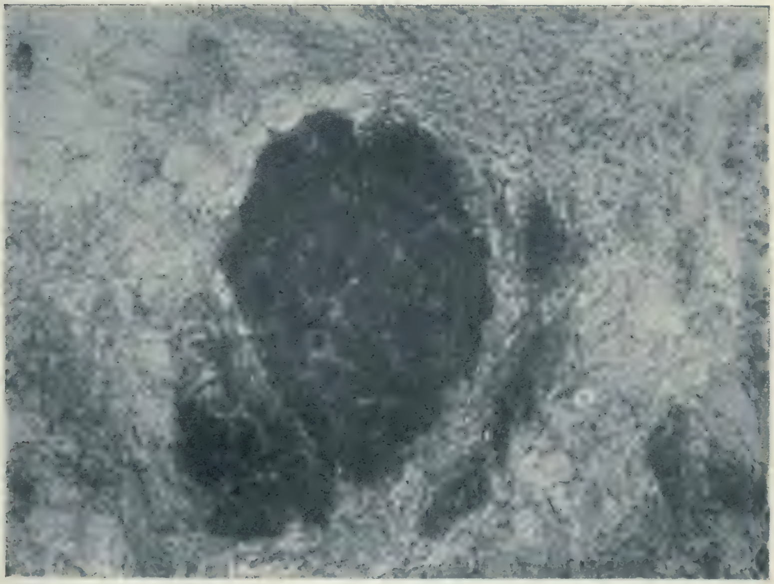

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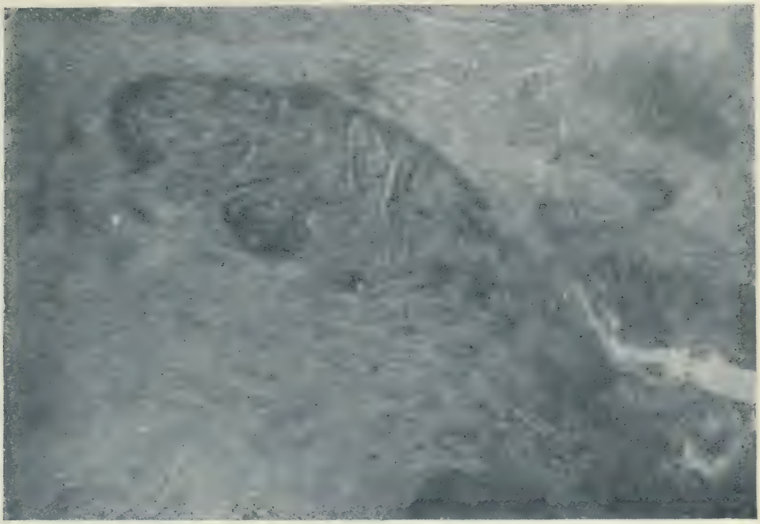

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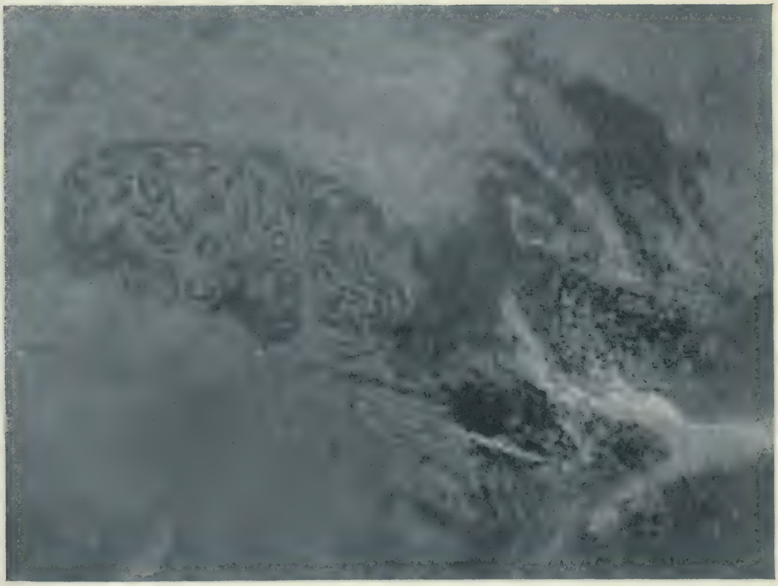

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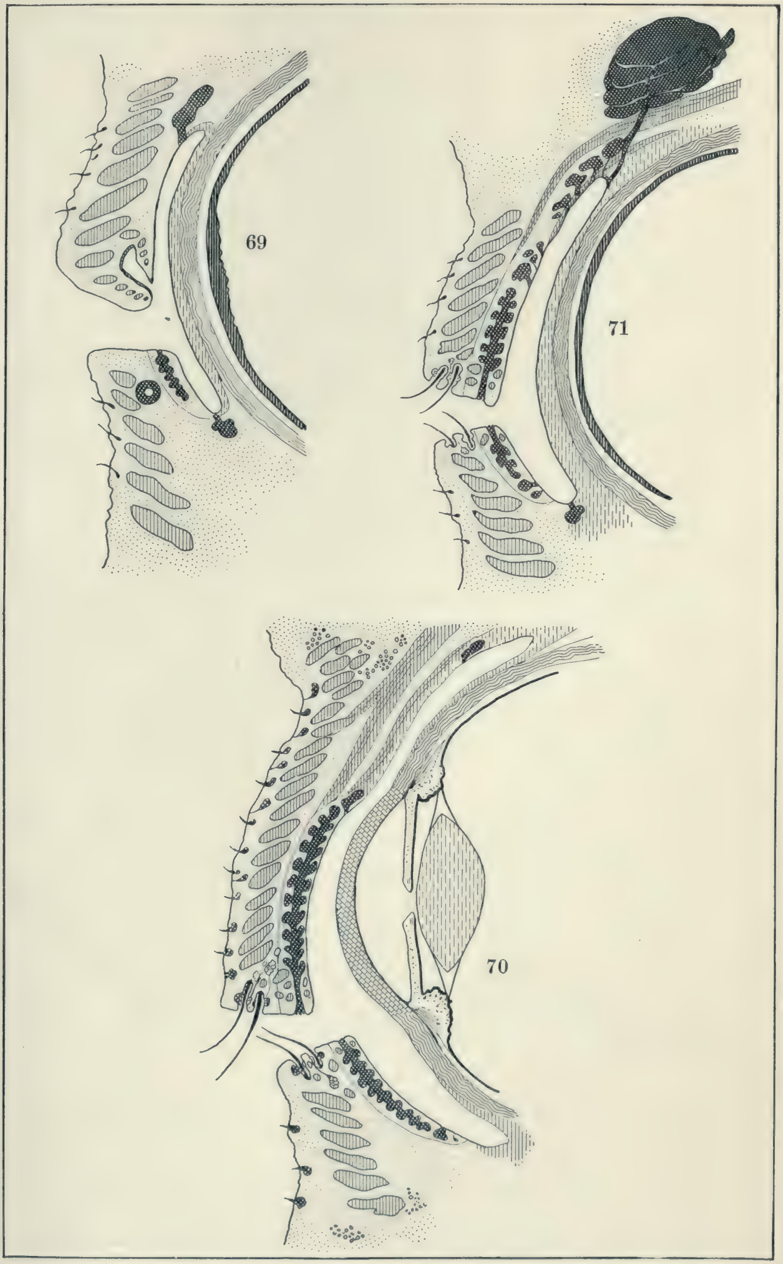

GLANDS APPERTAINING TO HUMAN EYE.

POSITIVE PHOTOGRAPHY, WITH SPECIAL REFERENCE TO ECLIPSE WORK.*

FRANCIS E. NIPHER.

During the last year the writer has been making an attempt to adapt the process of positive photography to service in the two solor eclipses which occur during the next two years.† The unusual duration of the period of totality in both, makes them peculiarly favorable to the use of such a process. And while this will also be to some extent an advantage in securing negatives, still an over exposure is then always possible. When such over exposure is corrected by the use of a restrainer, the effect is to dissolve away the very details which the long exposure was intended to secure.

By great over exposure in the old sense of the word, and development in the light instead of in the dark room, no over exposure for positives is possible. The only limitation then is an under exposure, which causes the positive picture to fog.

The object of the present paper is, to give the present condition of the process, and to request any who may be able to do so, to aid in so improving it, that the best results may be secured in these eclipses. There will be no other opportunity so favorable in the next generation.

Let the stop of the camera be set at No. 8 of the universal system. The ratio of focal length divided by diameter is then

$$\frac{f}{d} = 4\sqrt{n} = 4\sqrt{8} = 11.3.$$

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* Presented by title to The Academy of Science of St. Louis, October 15, 1900.

† These Transactions, Vol. **10,** No. 6. — Nature, **1900.** July 12, p. 246; Aug. 9, p. 342; Aug. 23, p. 396. — Am. Journ. of Science, July, 1900, p. 78.

If the object to be photographed is a landscape, consisting mainly of mid-summer foliage, and the plate be a fast plate, like the crown plate of Cramer, the exposure may be made two to four minutes in length. For the first attempt the latter interval is to be preferred. The exposure may be made as much longer as may be desired. It has been successfully tried with exposures of six and eight hours.

The plate is taken to the dark room and is best developed by the light of a strong lamp. If the exposure has been not over two minutes, the best result will be obtained by placing the bath between two strong lamps. Two Argand or Rochester burners with porcelain shades in contact or nearly so, with the bath in a position of strongest illumination between and below the shades, is an admirable arrangement. The bath should be cool at the start, and it should be in ice-cold water during the development. The bath being rather weak, the development will go on very slowly.

Various developers have been tried. Pyro has given very poor results, although the same bath would yield brilliant negatives in the dark room. By far the best results have been reached by the use of Cramer's hydrochinon developer, the formula for which may be found in every box of Cramer plates. This formula is:—

SOLUTION NO. 1.

	Ounces.	Grammes.
Water	25	1000
Sulphite of soda	3	126
Hydrochinon	$\frac{1}{2}$	21

SOLUTION NO. 2.

	Ounces.	Grammes.
Water	25	1000
Carbonate of soda	6	252

The two solutions are to be mixed in equal parts, when used, and are to be diluted to from one-third to one-fifth strength. A few drops of ten per cent. solution of bromide will give brilliancy to the plate, but will not improve definition of details. The bromide may be left out.

In transferring the plate from the holder to the developing bath, it would seem to be somewhat better to turn the lamps down until the liquid covers the plate, but the light should then be turned on at once. When lamp-light is used this precaution is not very important. In fact the writer is inclined to say that such precaution is not then necessary. If the exposure has been too small, either from insufficient light on the object, or from insufficient time, such an exposure in the light-room is a decided advantage. It carries the plate farther from the zero condition, and materially improves the picture. The same result may be secured by turning the camera upon the sky after the usual exposure to the object has been made, and before the shutter has been closed. This sky-exposure may be for half a minute with a No. 8 stop, but should not exceed this. The following experiment seems to indicate that this sky exposure should be after rather than before the exposure to the object.

A white paper was pasted on a somewhat larger card of dead black. It was placed against a brick wall in sunlight, and with a cloudless sky. After a minute of exposure to the plate in the camera, the black card was quickly shifted laterally by a distance slightly greater than its width. This was repeated ten times in an exposure of ten minutes. On developing, the first of the ten exposures was somewhat more distinct than those which followed, but between the others no difference could be detected. The last minute of the ten was as effective as the second. But when the experiment is terminated at the end of the first minute, the image is very indistinct. It is evident that the subsequent exposure during the nine minutes served to make more distinct the image of the card made during the first minute. And since the plate seems to be somewhat more sensitive at first than it is later in the exposure, it is better to utilize this part of the exposure in securing details of the object, rather than in fogging the plate beyond the zero condition. This difference of sensitiveness is not very marked. It is difficult to see any difference in the first three and the last three minutes of a six-minute exposure. This may be shown in an interesting way by the following experiment. The experimenter should preferably be dressed in light-colored clothing, and should train the camera on a grass-covered hill, which will serve as a background. Any other dark background will of course answer the purpose. After snapping open the shutter, walk to a point about 100 feet distant, the camera having been focused for that distance, and stand motionless for two or three minutes. Then step sidewise four or five feet and stand for an equal time. Then walk back and close the shutter. The two figures will seem practically alike if the sunlight has not changed, and the darker background will not appreciably show through them. The plate will show no trace of the motions, and the figures will be as clear and distinct as in a good negative.

Of course the same thing can be done in the ordinary negative process by so arranging the conditions that the time of exposure is sufficiently lengthened.

In order to make the positive photography as useful as possible, it is necessary to find a developer which will bring out a clear positive with as small an exposure as possible. It seems certain that it must differ from any developer used in ordinary photography. The method of restraining an over-exposed negative is known, in order that it may be developed as a negative. If we consider this plate as an under-exposed positive, how shall it be pushed along over the zero condition, and developed as a positive? That answer may be given in part. It must be developed in the light. A poor negative may be developed in a lighted room, and a poor positive may be developed in a dark room. These are not the conditions which yield the best results.

The writer had great expectations of the developer used by Waterhouse for producing positives in the dark room with ordinary exposures. The formula for this developer, as given in various works on photography is: —

		Parts.
A.	Eikonogen	5
	Sulphite of soda	10
	Water	100
B.	Carbonate of soda	4
	Water	100
C.	Phenyl-theocarbamide	1
	Water	2000

For developing take of A 1, of B 2, of C 1 and of a 10 per cent. solution of potassium bromide 1. If the contrasts are too strong, a few drops of ammonia may be added.

This developer was said to produce a positive in the dark room, with ordinary exposure. It was hoped that this urea salt either in the Waterhouse developer, or in some other, and with development in the light, might shorten the camera time very greatly.

When the exposure is normal for a negative, and the plate is developed in the dark room with this developer, it is found that a yellow to orange coloration appears in the shadows. If there are contrasts on the object, the high-lights look as they do in an ordinary negative. The roof of a building and the sides lighted by direct sunlight appear as in an ordinary negative. Light and dark strips of slate will appear reversed. The sky is dark. The sides in shadow are of a yellow or orange color, sometimes almost red, and appear as positives. If the exposure is increased somewhat either by an increase in time, by stronger illumination of the object, or by using a larger stop opening, the coloration disappears, and the whole picture is seen to be a negative. A still greater exposure being made, the picture approaches, and finally becomes a zero result. Nothing develops on the plate. With a still longer exposure the picture is reversed, and a real positive develops. This picture can be developed in the light. This is not the case with the Waterhouse pictures. They look like positives, as any negative may be made to look like a positive, but they should be called pseudo-positives. They are not due to a real reversal. They are moreover somewhat disappointing in appearance. It is only too evident that this Waterhouse process does not seem to be a very promising field for application to eclipse photography, although it presents some very interesting illustrations of different forms of silver.

The most promising field for investigation at present consists in the application of some transforming process to the film, after it comes from the camera, and before the picture is developed. Various oxidizing agents have been tried with different degrees of success. The most satisfactory of these oxidizing solutions is a mixture of nitric acid and potassium bichromate in rather dilute solution. There is no trouble in getting very satisfactory results with four minutes of exposure and a No. 8 stop. It seems very probable that by varying the proportions of this transforming solution, and perhaps varying the oxidizing agents themselves, such exposures as are now given in the negative process, may yield good positives. The field open for experimentation along these lines is very wide. The degree of illumination while in the transforming solution, and the time interval for the transforming process, are involved. The desirability of perfecting these processes at the earliest possible moment, leads the writer to urge those who have had wider experience in photography to lend a hand in this work. If fine details can be secured in a positive with a camera exposuie such as is now required for a negative, then certainly there is great reason to hope that by exposing a plate during the whole time of totality in the long eclipses which will shortly take place, we may hope to secure better results than the present methods can give. In positive photography there can be no over exposure. In negative photography, over exposure is an approach to a zero condition. In positive photography the zero condition has been passed.

Issued October 24, 1900.

THE FRICTIONAL EFFECT OF RAILWAY TRAINS UPON THE AIR.*

Francis E. Nipher.

The effect of any medium in retarding a body moving through it, has been very carefully studied in connection with moving ships and trains of railway cars, and in various other ways. In train resistance it is well known that the effect of the air is made up of end effects, and of side effects. The end effects are the result of the compression at the head end and the rarefaction at the rear end. These retarding effects are independent of the length of the train. The side effects are due to the viscocity of the air. They are in the nature of a shear. The resistance to the train due to this cause, is directly proportional to the length of the train.

That the air in contact with the sides of a train has an appreciable effect in resisting its motion, carries with it as a necessary consequence, the dragging of air along with the sides of the train. This phenomenon is well known. It has long been known as a source of danger in connection with fast trains. At least eighteen years ago the writer witnessed with some surprise the frantic efforts of a station agent of the New York Central Railroad to drive everybody from the platform to the interior of the station building. The fast train from New York was due, and it soon passed at full speed. I declined to leave the platform, and discovered the reason for his behavior when the train passed. The draught of air which accompanied the train was sufficient to cause serious alarm. The agent afterwards explained to me that serious results might follow such imprudence as I had shown.

* Presented, and read by title, at the meeting of The Academy of Science of St. Louis, of October 15th, 1900.

Some years later I arranged a device with which to test the conditions in this air-draught. It was built after the plan of the rotating anemometer used by the Weather Bureau, excepting that the four hemispherical cups were replaced by thin flat metal plates. The rotating system was very delicately mounted, but in an ordinary wind, there was rotation only as a result of eddy motions in the air. In the long run, the slow rotations in opposite directions canceled each other.

A top view of the rotating part is shown in the adjoining figure.

The four cross arms, having the flat plates at their outer ends, were of No. 6 brass wire, and they were braced by a steel wire which connected their outer ends. The distance from center to center of opposite plates was one foot, and the plates were four inches square.

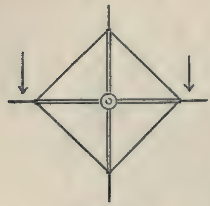

Fig. 1.

When this differential anemometer is brought near a building against which the wind blows obliquely, it begins to revolve. This revolution is due to the fact that the velocity of the air sheet sweeping over the surface, is less, the nearer the face of the building is approached. When held out of the window of a moving train, the system is put in rapid rotation.

The plate nearest the car is shown to be in wind of less velocity, than those further out. This shows that air is being dragged along by the train, and that the concentric layers of air around the train are shearing on each other.

On one occasion the apparatus was carried into the country three or four miles west of Iowa City, and planted on the ground near the track of the C., R. I. & P. R. R. It was so placed that the fast train from Chicago, passed at a distance of four inches from the vane nearest the track. The plane of the vanes was about a foot above the bottom of the car. The observer lay down near the track in order that there might be no doubt about the question of actual collision of the train with the apparatus. The distances were as had been planned. The effect of the blow from the air when the train passed was to break the small steel brace-wire, and to bend the arm carrying the nearer plate until it nearly touched the arm 90° distant. The opposite arm was also somewhat bent in an opposite rotational direction.

A number of cases of chickens being entangled in the air draught of a train have come to my attention, but some doubt naturally arises in such cases. It is possible that misdirected efforts on their part may have contributed to the result. A better illustration is found in an incident related to me by an eye-witness, Mr. T. J. Foster, of Hannibal, Mo., who in 1896 was conductor on train No. 81 of the St. L., K. & N. W. R. R. Some time near the year 1890 he was on a train passing without stop through Paris, Mo. A number of excelsior bed mattresses six inches in thickness were each tied in a roll and were standing on end on the station platform, about twelve feet from the track. They were tumbled over by the air draught of the train and rolled under the train. The trainmen made the greatest efforts to bring the train to a stop in order to prevent derailment.

It is evident that these objects were toppled over by the blow of the air current, and that they were given a rotation in falling, by being struck a little harder on the side nearest the train. After they had fallen over, they were kept in rotation because they were still in the current of air. The moment of the force producing the rolling motion was in this case relatively large, because of the large diameter of the masses. Smaller masses on the ground would be less affected because of the smaller leverage, and because the air current near the ground is less rapid than at some distance above the surface. The effect of the earth's surface in retarding winds has been well known for many years. Nevertheless, I have seen pieces of coal an inch in diameter rolled along over the surface of the ground by train draught.

This subject was called to my special attention by the death of a little boy, James Graney, under circumstances which made it seem probable that his death had been brought about by the action of the air-draught of a rapidly moving train. The evidence showed that he was about to cross a railroad track at a public crossing in St. Louis, and that he was on the plank approach to the track. The surface of the approach was flush with the tops of the rails, and sloped gently towards the track. An approaching train giving no warning signals was hidden from view by cars on a switch track. Under the ordinances, the speed of the train was limited to six miles per hour, and it was admitted by the trainmen, none of whom knew anything of the accident when it occurred, that the speed of the train exceeded this limit. Other evidence of those who saw the accident, showed that the speed was very great. It was shown that the boy was not hit by the train. The fact that the upper part of his body was without injury, was corroborative of this evidence. He fell over after part of the train had passed, falling in the general direction of the train, and rolled under the wheels. In the first trial the writer gave it as his opinion that the blow from the air current would be sufficient to topple him over, and give him a sufficient tendency in rotation to roll him towards and under the wheels; and further, that this action would not have been appreciable if the train had been running at a speed of six miles per hour. The jury and the Supreme Court accepted this explanation,* but the case was sent back for retrial on account of other evidence.

A report of the evidence obtained wide circulation, and as a result, the writer received a marked copy of a Paris paper, giving an account of the evidence, and stating that a French soldier had recently been killed in a precisely similar way. With several companions he had been surprised by a high-speed train while in a cut having masonry walls. All but one made their escape from the cut. He backed against the wall and out of reach of the train. He was, however, swept along and under the wheels.

In the second trial Professor Woodward testified in corroboration of my testimony. No contesting evidence upon the points covered in our testimony was offered by the railroad company in either trial, but the Supreme Court on the second appeal,† reversed the action which it had taken on the first appeal.

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* Graney v. St. L., I. M. & S. R. R., 140 Mo. 89.

† No 9820. Graney et al., Resps. v. St. L., I. M. & S. Ry. Co., Applts., 57 S. W. Reporter, 276.

The matter having now ceased to be a subject of judicial consideration, it will not be indelicate to publish the results of experiments upon which the evidence was based, and which could have little meaning to a jury. This seems now to be doubly important as a matter of public safety by reason of the opinion of the court, that the danger here pointed out does not exist.

It may first be explained, that, although probably more common than is supposed, such accidents are not very common. No person of mature years, and unfamiliar with train effects, would voluntarily place himself as near a moving train at high speed, as is necessary to result in danger. The danger comes when one not familiar with trains is taken by surprise, and becomes terrified. Trainmen think nothing of standing on the ground between a stationary train and one passing at full speed. They know exactly what to expect and they even unconsciously prepare for it. They habitually take risks as great as those of war. But one who is surprised in such a position, and who fears for the result, is in serious danger. He should lie down or get upon his hands and knees, in which position he will be safest. All four-footed animals, particularly if they are small, are also on a stable base, and are therefore in comparative safety.

The differential anemometer before described is not easily calibrated for precise measurements on account of the element of friction. It was therefore determined to make a direct measurement of pressure due to the velocity of the train, at various distances from the train. For this purpose a hollow cylinder of brass served to collect the pressure. The open end of this tube collector was directed towards the head of the train, and the wind pressure in the collector was carried through a small hole in the bottom by means of a rubber tube, to a water gauge in the car.

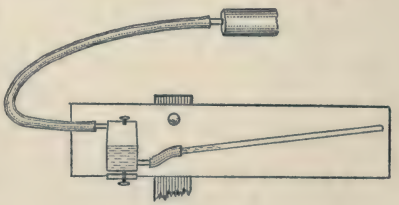

FIG. 2.

This gauge consisted of a closed cistern of water, having an inclined glass tube leading out from the bottom. The air pressure was transmitted from the collector to the air chamber above the water in the cistern, and an increase of pressure was shown by the rise in the level of the water in the inclined tube. The whole apparatus was carried on a carpenter's clamp of wood, which could be clamped to the window sill of the car. The cistern and inclined tube were pivotally mounted on a standard attached to the clamp, and furnished with a level and with a duplicate tube and cistern which served also as a level. By this means the frame carrying the cisterns and tubes could be kept in level while readings of pressure were being made. The collector was mounted on a light wooden channel-bar, sliding in guides attached to the clamp. The rubber tube was laid in the channel of this bar. The bar could be thrust out to various distances, so that the collector could be set to a known distance from the side of the car. This distance could be varied from 0 to 30 inches. At the former distance the axis of the collector was at the general surface of the car. The wooden channel-bar was occasionally broken by collision with bridges, and a supply of such bars was always carried.

The measurements were made on passenger trains and on freight trains on various roads. Many trips were made from St. Louis to Burlington, on the St. L., K. and N. W. R. R. and from St. Louis to Chicago and Cairo on the Illinois Central. Some work was also done on the St. Louis and San Francisco and on the Wabash railroads, where advantage was taken of journeys on other business. The officials of all these roads afforded every assistance in the prosecution of this work. The Illinois Central R. R. finally fitted up a special car which was delivered to us at East St. Louis, and it was placed in any part of any train we might select upon this road.

The greater part of one summer was devoted to the study of various wind pressure problems by means of this car, which was in motion during most of the daylight hours of every day.*

During most of this work, the open end of the pressure

* Trans. Acad. Sci. of St. Louis, No. 1, Vol. VIII.

gauge, communicated with the air in the car. The car windows and doors were open, and the measurements were usually made at the middle of the car. In the special car, the open end of the manometer was connected with a tank of standard pressure, in communication with an Abbe collector above the top of the car. There was no substantial difference in the results obtained by these various methods.

It is evident that if the air around the car were being carried along with it at the same velocity as the car itself, the gauge should show no pressure. A person standing on the ground near the car would then feel a gust of wind, blowing with the velocity of the car. If the air near the train is being carried along by the car, but lags somewhat, the pressure measured from the car will correspond to this lag, or slip of the air upon the car. If the observation could be made from the ground, the mouth of the collector being turned in an opposite direction, the pressure collected would be due to motion of the air, dragged along by the train.

Let $P =$ the pressure corresponding to the velocity of the car. This would be the pressure shown by the gauge, if the collector were thrust far out from the car into the undisturbed air. This distance to which the collector must be thrust in order to collect the pressure P, is really infinite, but at a comparatively short distance this pressure is nearly attained.

It is not uncommon to see hats blown from the heads of people standing 25 feet from the track, by the air-draught of a fast express train.

If the collector be thrust out to a distance d from the side of the car, the pressure will be some pressure p, smaller than P.

In the diagram, $O\ p$, represents the side of the car, and is taken as the axis of pressure. $O\ d$, is the axis of distance from the side of the train. The pressure at the car surface, as shown by the

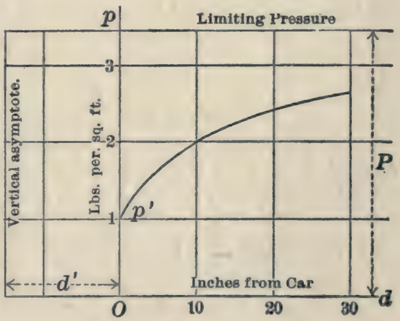

Fig. 3.

gauge within the car, is represented by the line $O\ p'$. The rise in the curve passing through p' shows how the pressure rises, as the collector carried on the car is thrust further out. As the distance d increases the pressure approaches the limiting value P, corresponding to the speed of the train. This is represented in the figure by the horizontal line at the top of Fig. 3. The curve approaches this line of limiting pressure, as d increases.

The distance from this line of limiting pressure, down to the curve at any distance d, represents the pressure against an object standing on the ground. The way in which this curve drops from this horizontal line as the vertical axis is approached, shows how the train-draught increases as one approaches the train. Measured from the ground, the pressure on the windward side of an object due to train-draught at the distance d from the train is $P - p$, while measured from the train the pressure in the opposite direction is p.

This curve as determined by the observations satisfies the equation of an hyperbola. The vertical asymptote is within the car a distance d'. The equation of this hyperbola is evidently

$$(P - p)\,(d' + d) = c. \qquad (1)$$

In this equation P. d' and c are constants to be determined from the observations. The value of P is of special importance. Its relation to the velocity of the train is represented by the well-known equation of Newton

$$P = \frac{\delta}{2}\,v^2 \qquad (2)$$

where δ is the density of the air. When v is expressed in centimeters per second and P in dynes per square centimeter, the value of $\frac{\delta}{2}$ at ordinary temperature and pressure is 0.0006. When v is in miles per hour and P is in pounds per square foot the equation becomes

$$P = 0.0025\,v^2. \qquad (3)$$

THE SUCTION CASE.

From the St. Louis MIRROR, November 29th, 1900.

There has been published as No. 10 of Vol. X. of the "Transactions of the Academy of Science of St. Louis," a pamphlet upon "The Frictional Effect of Railway Trains upon the Air," by Francis E. Nipher, of Washington University. The brochure is remarkable, as it is practically a scientific reply to a decision of the Supreme Court of Missouri in what is known as "the suction case." In that case the matter at issue was whether a boy ground to pieces by a train had been drawn under the wheels by being sucked into the vacuum created by the rapidly moving cars. The Court decided that rapidly moving trains of cars do not act upon the air around them in such a way as to endanger the lives of those about them. Professor Nipher was an expert witness in the case. He and Professor C. M. Woodward testified against the defendant railroad, that rapidly moving trains did create a suction that might draw a person too near the track under the wheels. The Court made sport of Professors Nipher and Woodward in its opinion. The language of the opinion, even charitably construed, implied that the court believed the distinguished experts to be very disreputable men, willing to testify to things of which they were ignorant. The Court, astonishingly enough, put upon record, in its opinion, a similarity which it claimed to have discovered between the conduct of Professors Nipher and Woodward and that of a fallen woman. The Court appears to have agreed that the suction performance was an invention of the experts for the plaintiff, that the theory and fact of this train action was unheard of, although the record of the case does not show that the defendant railroad put forward, during the trial, a single witness to contest the expert evidence. The Court held that even if this alleged train action on air did exist, it was unknown, and the railroad should not be held responsible. The contention of the plaintiffs and the experts was, that the suction necessary to draw a boy under the wheels could only be created by a train running at a rate of speed vastly greater than that authorized by law within the limits of the city. The evidence of the train-crew established the fact that the train was running at an unlawful speed, when the boy was seen to topple over, without being struck by the train, and roll under the wheels. The Court said that the testimony did not disclose any way by which the railroad company might have "provided against" the accident, if due to air currents. The evidence was, however, that the railroad company might have made this accident impossible, by the simple expedient of obeying the law. The lawful limit of speed was six miles per hour. The Court, on a first hearing of the case on appeal, reversed the trial court, because of other evidence—not that of the experts—improperly admitted. In all the trial no railroad man controverted the experts' declaration, although the company might have summoned many of its own oldest employes to testify on that point. Yet, when the case was tried a second time and again resulted in a verdict against the company, the Supreme Court attacked the experts it had approved in the first reversal and threw out their uncontested evidence. The record of reversal stands, an attack upon the character of two worthy gentlemen and honest, scientific investigators, against which they have no redress, for they cannot even attempt a defence in the record in which they have been wronged. Professor Nipher's paper, just published by the Academy of Science, contains the overwhelming scientific demonstration, beyond all doubt, that every word to which he and Professor Woodward testified was true. Train suction is a fact and train suction is sometimes, at certain speeds, strong enough to draw a boy or even a grown man, under the wheels. The thing is as well demonstrated as that two and two make four. But the Supreme Court of Missouri—wonderful Missouri, where they must be "shown" and even then they deny the truth—says that there "aint no sich thing!" Talk about Rev. Jasper's "the sun do move!" Talk about the mythical Papal bull against the comet! The Missouri Supreme Court decides that the physical laws of the universe don't exist, so far as that august assemblage is concerned. It is apt to decide against the solar spectrum, against the law of gravitation, against the sphericity of the earth, or against the multiplication table, any old day. But, great though the Missouri Supreme Justices may be, superior though they be to the facts of science, it is fortunate that experimental determinations of wind pressure are not likely to be affected by legal opinions—themselves, often, fearful and wonderful examples of wind pressure—that such pressures do not exist. The profound jurists of the Missouri Supreme Court are reminded that there is nothing in history to indicate that any proposition in mechanics was ever either established or reversed by legal opinions, by offensive personalities or by a combination of both. Professor Nipher's brochure is Galileo's *E pur si muove* over again. And it had to happen in Missouri.

These equations were tested by making observations on fast passenger trains which made long runs at fairly uniform speed. The bar carrying the pressure collector was continually varied in position through the limit from 0 to 30 inches as is shown in the following table. In this table the values of the pressure corresponding to the various positions d, are each the means of 87 separate determinations. The number of measurements represented in this table is therefore $11 \times 87 = 957$.

Inches. d.	Lbs. per Sq. Ft.		Diff.
	p obs.	p calc.	
0	0 95	1.02	—0.07
1	1.16	1.16	0.00
2	1.30	1.31	—0 01
3	1.44	1.43	+0.01
4	1.59	1.53	+0 06
5	1.67	1.61	+0.06
10	1.96	1 98	—0.02
15	2.17	2 22	—0.05
20	2 36	2.38	—0.02
25	2 49	2.52	—0.03
30	2.66	2 62	+0 04
∞	....	3.42	....

The values of P, and d' in equation (1) were computed by the method of least squares, since the form of the equation did not easily lend itself to graphical solution. The equation may be put in the form

$$pd = a + Pd - d'p$$
$$\text{where } a = Pd' - c.$$

The normal equations for a, P and d' are respectively,

$$\Sigma\, pd - na - \Sigma d.P + \Sigma p.\, d' = 0.$$
$$\Sigma\, pd^2 - \Sigma d.a - \Sigma d^2\, P + \Sigma\, pd.d' = 0.$$
$$\Sigma\, p^2d - \Sigma p.a - \Sigma\, pd.P + \Sigma p^2.d' = 0.$$

From these equations d' and P were found by elimination. The value of c was then computed from the observations by substituting these values in equation (1).

The average value of c and the values of P and d' being substituted in (1) the value of p for each value of d is computed. These values are given in the third column of the table.

The vertical asymptote of the curve is inside of the car surface a distance $d' = 15.1$ inches, and the limiting pressure which would be observed if the collector were thrust far out into the undistubed air is $P = 3.42$ lbs. per square foot.

The measurements of the last table were made in the rear of the fourth car from the locomotive. They covered the distance from St. Louis to Burlington and return. The actual distance covered while the measurements were being made was 316 miles, during 7.88 hours, not including stops. The average velocity of the train was 40.1 miles per hour. The average weighted v^2 was 1746. The square root of this value, the virtual velocity, is 41.7. The constant in equation (3) is by this determination

$$\frac{P}{v^2} = \frac{3.42}{1746} = 0.0020—.$$

The velocity of the train was determined by timing its passage through all stations which could be identified, and by timing its arrival in and departure from all stations where stops were made. During this trip the wind was very light from the East while going from St. Louis to Burlington. On the return trip the wind was from the N. W., with a velocity of from 6 to 12 miles per hour. This would make the effective velocity somewhat less than that of the train on the return trip.

A decrease of 4.7 miles per hour in the $\sqrt{\text{mean square}}$ velocity produced by a following wind, would account for the reduction of the value of $\frac{P}{v^2}$ from 0.0025 to 0.0020.

The effect of a wind blowing transversely across the train, in an open country, is to largely obliterate the phenomenon of train draught. The air drifts away from the train too quickly to be set into motion by the successive action of all the cars in the train. The effect then appears and disappears as calms and gusts of wind alternate with each other. In a timbered region, or along the banks of the Mississippi river, where the bluffs and timber check the air current, the phenomenon is always present. The locality where James Graney was killed was eminently favorable to the production of train draught, even with a transverse wind.

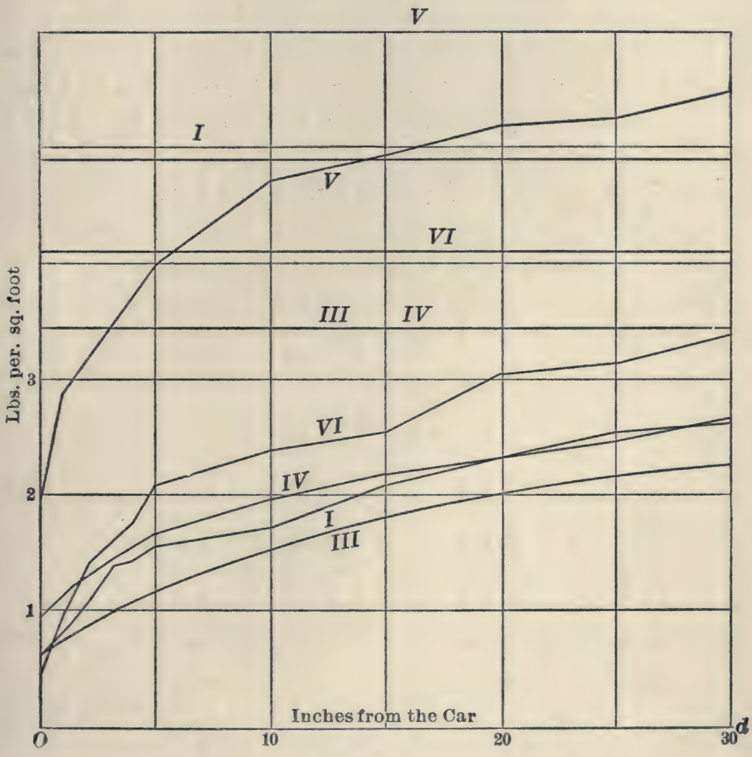

FIG. 4.

The effect of a wind blowing against any object, is the result of the compression on the windward side and the rarefaction on the leeward side. The cup-shaped collector used in these measurements, gives only the compression. The effective pressures acting on any object like a pressure board, are about thirty-three per cent. greater than those computed by Newton's formula.*

* These Transactions, Vol. VIII, No. 1, p. 19.

The work done on a number of other trips has been similarly reduced. All give very satisfactory results. A few in which the effect of wind was least, have been used to check the constant of Newton's equation. The results of the observations are shown in Fig. 4, which is the same in character as Fig. 3. The different curves are indicated by Roman numerals, which correspond to the number of car-lengths from the locomotive tender to the point of observation. For example, curve I represents observations made one car-length from the tender of the locomotive. The horizontal line representing the limiting pressure is also marked I. Similar explanations apply to the other curves of Fig 4. The curve of Fig. 3 is reproduced in Fig 4, where it is indicated by the numeral IV. Additional data concerning these curves are given in the adjoining table.

Curve.	v.	*No. obs.*	d'.	P.	$K=\frac{P}{v^2}$	Remarks.
I.	46.0	21	10.5	4.90	0.0023	No wind.
III.	38.3	36	20.4	3.42	0.0023	No wind.
IV.	41.7	87	15.1	3.42	0 0020	Light following wind.
V.	44.7	18	5.4	6.01	0.0030	Light head wind.
VI.	42.5	10	8.5	4.11	0.0023	No wind.

The column headed curve gives the number of the curve in Fig. 4, and also the number of car-lengths from locomotive to the point of observation. The next column gives the $\sqrt{\text{mean square}}$ velocity of the train. The third column gives the number of observations of p, to obtain a mean p, for each of the eleven positions of the collector. In the final column the remarks: No wind, means a very light wind, variable as regards velocity and direction. It was thought at the time of making the observations that it was not appreciable as a factor.

A very large amount of work which has been done has not been included in these reductions. In some cases the wind was so strong as to greatly disturb the measurements. It was found to be impossible to eliminate this effect. The wind velocity could not be determined at stations where the train came to rest, under the conditions which hold along the track between cities. Only such work is included in the present paper, as might be expected to lead to a fair approximation to the constant in Newton's equation.

The investigation of this subject was made possible by the co-operation of Mr. W. W. Baldwin, president of the St. L., K. and N. W. R. R. and of Mr. A. W. Sullivan, General Superintendent of the Illinois Central Railroad. Assistance in making the measurements was also given by my colleague, Professor Engler.

Issued November 12, 1900.

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