we dare not think of separating them. If one experiments he keeps the mathematical laws in mind; if he studies the subject mathematically he keeps the physical laws in mind. A problem in one is also a problem in the other; both are rigorous and develop the reasoning powers, but sometimes it is easier to handle the experimental than the analytical method.

In the MONTHLY WEATHER REVIEW for 1897 will be found a splendid memoir on the "Equations of hydrodynamics" arranged for the study of the general circulation of the atmosphere. This and the corresponding solution of the complex differential equations give the mathematician more than he can handle at present, but the suggestive paper by MacMahon, read at the recent International Scientific Congress, on the $n$-fold Riemann surface, opens up great hopes for the future.

Meanwhile we must mingle experiment and theory; each must guide the other. The physicist may, in his laboratory, carry out some of the following experiments and at a glance perceive the resulting atmospheric motions, or the solution of the differential equations under any given special conditions that the analyst would find it difficult to attain, but can easily confirm when once the result is known.

We may experiment on small local motions before proceeding to the larger ones.

In a large room, or in a case with double glass walls, so that the inside temperature may be controlled, let a shallow stream of cool air flow along the bottom. By giving this a slight but adjustable slope the rate of flow may be regulated; by altering the bottom we may pass from water or smooth sand to wavy, rolling prairie or ranges of hills and mountains. We may imitate every variety of ordinary atmospheric motion.

By utilizing a layer of $CO_2$ for the bottom we may even study the flow of upper air currents over lower ones.

We make all these movements visible by introducing a little smoke, but especially by applying the so-called "Schleier" method of Foucault, as perfected by Mach and Dubois, which enables us to photograph the feeblest differences of density, whether due to pressure or temperature or moisture.

Among other problems in aerodynamics should be mentioned that more elementary one, the hypsometric formula of Laplace. Our students and the surveyors and mountaineers use this with aneroids for determining altitudes, without understanding its derivation or the sources of mistakes in applying it, especially the uncertainty of our knowledge of the temperatures of the air. Now the formulas may be deduced analytically by integration of the simple differential formula or by algebraic or geometric or arithmetical or graphic method, and all should be combined as an illustration of the unity of logic in whatever form presented. Science is but logic applied to material nature.

I will merely mention some other problems that appeal to us from both analytical and experimental points of view.

The total resistance and the pressure and motions of the air all around a resisting plate, sphere, or other obstacle.

The action of the wind in producing "suction" at the top of an open pipe or chimney.

Among problems that may be handled first by pure mathematics and then by experiment and observation are the determination of the calibration correction of a thermometer, the protruding stem correction, and the Poggendorff Correction.

These belong to elementary physics, but will give your students a chance to apply their mathematics to physical problems.

A complex trigonometrical problem involving a slight knowledge of astronomy is the determination of the duration and intensity of sunshine or the total amount of heat received by a unit horizontal surface for any moment of the day and the year. The calculation is to be made for the outside of the atmosphere, because if we attempt to make allowance for the absorption by the atmosphere the problem becomes too complex for our present purposes. The simpler problem may be treated geometrically and graphically and is essentially a matter of familiarity with "the use of the globes," as it was called one hundred years ago.

Globes and charts are vital matters in meteorology and are elegant classics in geometry. Chartography and projections and the globes themselves are too much neglected—pushed aside by the crush of new demands for instruction in every other branch of knowledge; but they are absolutely fundamental to astronomy and meteorology, terrestrial physics, and all geographic relations, and I hope to see them properly appreciated in the schools of pure mathematics and terrestrial physics. The properties and methods of construction of various equal surface projections ought to be as familiar to a student as those of the ordinary stereographic projection. The problems of chartography are beautiful for the drafting room, but more vivid and better adapted to the comprehension of many persons if worked out on the globe itself; and one does not need an expensive globe; even a homemade globe or rubber ball can be very useful.

The globes and conic section *in solido* should be handled by your students at some early stage in their education.

But, finally, to return to our aerodynamics. Nothing can be more attractive to a student than the formation of a waterspout by Weyher's method and the study of the wind velocity and pressure, the barometric pressure, the temperature, and the dimensions of the cloud column.

We simply set a horizontal disk at the top of a room or closed case into rapid rotation. Soon the air beneath is dragged into rotation down to the very floor. Below we place a dish of water, and the vapor from it is drawn up into the inner revolving vortex while at the same time thrown out; eventually it descends and ascends in regular circulation. As the disk and air increase their rotary speed, the central vortex diminishes in barometric pressure while increasing in velocity, and the moist air flowing into it cools by expansion, forming a central waterspout column or vortex. Here we begin to be stirred with a desire to measure. We insert a long Pitot tube and determine the wind pressure at many points and chart the pressure or velocity on ruled paper.

We insert a pair of small plane plates as in my method of barometic exposure (see Meteorological Apparatus and Methods), and determine and chart the pressure at many points. We send a thermometer or thermoelectric junction exploring the vortex and plat the temperature, or we use some form of hygrometer and determine the dew-point. In fact we experimentally determine all the elements that enter into the structure of the waterspout and compare our observations with the theories that have been worked out by Ferrel and Bigelow.

I have said enough for the present. I hope to elaborate this effort to help the mathematician and physicist to find a new field of problems for their students. Thus they will help us to develop the talents of future meteorologists.

These are but special illustrations of the general law that thinking, seeing, and doing must go together. We learn by doing as much as by reasoning—each helps the other. Every theory or hypothesis or suggestion should be reduced to exact formula, exact experiment, exact measurement. Precision is the vital essence of all valuable knowledge.

I hope to live and see special schools of meteorology, special laboratories and mathematical seminaries devoted to this as to every other profession, but for the present at least I urge that you illustrate the value of and enliven the interest in your mathematical and physical courses by frequently quoting or proposing problems drawn from meteorology.

## THE STORM AND COLD WAVE OF DECEMBER 24 TO 29, 1904.

By WALTER J. BENNETT, Forecast Division, U. S. Weather Bureau.

A storm of unusual intensity, closely followed by a marked cold wave, crossed the United States from the 24th to the 29th. The weather maps showing the progress of this storm are of special interest and will be found on Charts XIII-XV.

At 8 a. m. of the 24th the storm center was near Roseburg, Oreg., with a central pressure of 29.42 inches. It then moved rapidly due east and at 8 p. m., was over southern Idaho, with a barometer reading of 29.56 inches, an area of high pressure having in the meantime advanced over Alberta. At 8 a. m. of the 25th the storm was central near Denver, Colo., with a pressure of 29.54 inches, and the northern high-pressure area had increased in intensity and moved southward over northern Montana, where for the next few days it remained nearly stationary while increasing in intensity. Barometric conditions were favorable for a sharp fall in temperature to the north and west of the storm center, and frost, in some places heavy, occurred in the central valleys of California, while western Montana experienced a cold wave with temperatures of zero or below.

During the 25th, the storm center moved in a south-southeasterly direction to the panhandle of Texas with pressure of 29.60 inches, and the cold wave covered Montana, eastern Wyoming, and western South Dakota. Continuing a south-southeasterly movement, the storm center reached central Texas by 8 a. m. of the 26th. The cold wave had advanced over South Dakota and western Nebraska, and had extended over Wyoming, northern Nevada, and southern Idaho, the line of zero temperature reaching the southern boundary of Wyoming. During the 26th the storm reached the most southerly point of its path, and recurved, changing the direction of its motion from south-southeast to north-northeast, while it increased in intensity and in rapidity of motion. At 1 p. m. it was central over southwestern Arkansas, and at 6 p. m. was near Little Rock, Ark. At 8 p. m. it was over southeastern Missouri with a barometer of 29.56 inches. Rain fell throughout the Mississippi Valley, and was particularly heavy in its southern portion. The cold wave had advanced as far south as Taylor, Tex., and Roswell, N. Mex., and covered Nebraska, Kansas, Oklahoma, the eastern portions of Colorado, New Mexico, the Dakotas, and eastern and central Texas. During the night of the 26-27th, the storm center continued its north-northeastward movement, increasing in intensity, and by the morning of the 27th had reached northern Illinois, with a barometric pressure of 29.24 inches. Heavy rains were general throughout the Mississippi and Ohio valleys, and rain and snow fell quite heavily in the Lake region. These were the first heavy rains that had occurred in the Mississippi Valley for several months, and were much needed. In the rear of the storm, the cold wave extended from North Dakota to the Texas coast, and from the Rocky Mountains to the Mississippi River, the greatest twenty-four hour temperature fall, from 60° to 6°, occurring at Springfield, Mo. Temperatures of zero or lower were recorded as far south as Concordia, Kans., and Pueblo, Colo., and a minimum of 36° below zero occurred at Williston, N. Dak.

During the 27th the storm moved in a northeasterly direction over northern Illinois and southern Lake Michigan. The center was near Chicago, Ill., at 1 p. m., and at 8 p. m. was over southern Lake Michigan. Milwaukee, Wis., recorded the unusually low barometer reading of 28.84 inches. High winds were experienced at all Lake stations and throughout the Ohio and upper Mississippi valleys, Chicago recording a wind velocity of 72 miles an hour from the southwest. The high winds caused much damage to property along the Lake shores, houses were unroofed, and telegraph and telephone lines suffered severely. Telegraphic communication was entirely cut off over the Lake region and the Ohio and upper Mississippi valleys for twenty-four hours, and several days elapsed before the lines could be put into good working order. The heavy snow that accompanied this storm in many sections blocked trains and street cars. The cold wave covered the Mississippi Valley from Minnesota to Louisiana and extended to the Texas coast.

During the night of the 27–28th, high winds continued over the Lakes, while the storm center was passing over the Michigan Peninsula and Lake Huron. At 8 a. m. of the 28th it was near Rockliffe, Ont.; a secondary center had developed over the Atlantic coast near Long Island, and high winds were reported from all coast stations. Several vessels were wrecked near Hatteras, N. C. The cold wave extended from the Mississippi Valley nearly to the Atlantic coast, the line of zero temperature reached as far south as Keokuk, Iowa, and freezing temperatures were reported from all Gulf stations except in southern Florida and extreme southern Texas. During the day the storm center passed down the St. Lawrence Valley and high winds with snow continued on the New England coast and in the lower Lake region. The cold wave covered the lower Lake region and the middle and south Atlantic coast, but no very low temperatures were recorded in those districts. On the 29th the storm passed off to sea, colder weather followed in the Atlantic coast States, and the cold wave reached central Florida, with killing frost at Jacksonville and Tampa and a temperature of 38° at Jupiter.

## SOME RELATIONS BETWEEN DIRECTION AND VELOCITY OF MOVEMENTS AND PRESSURE AT THE CENTER OF ELLIPSOIDAL CYCLONES.

By STANISLAV HANZLIK, Ph. D., Prague.

Loomis in his "Contribution to Meteorology," Chapter I, on areas of low pressure, tried to find out the causes that produce the different velocities of progression of lows. He selected for that purpose those lows moving more than 1000 miles and less than 240 miles in twenty-four hours whose pressure at the center changed very little (.02 inch) or not at all during the twenty-four hours considered. He tabulated rain, wind, pressure of the following high, and changes of pressure in twenty-four hours at the first station and also at the second station; the first station being the location of the low when first observed, the second station its location twenty-four hours later. One of the results of this investigation was to show that the rate of progress of low pressure areas is proportional to the changes of pressure on the first and second stations. Whether the lows that he compared exhibited any similarity, such, for instance, as similar forms of isobars, or whether they were primary or secondary, Loomis does not mention.

In this paper I have taken for investigation the opposite case; leaving the changes of pressure at the first and second stations out of consideration, I tried to find out whether there are any relations between the rate of progress and the change of pressure in the center of the respective lows, and how far it depends upon the azimuth toward which the low moves. I selected for that purpose, from the semidaily manuscript weather maps of the Forecast Division of the Weather Bureau, cyclones of different velocities, ranging from 50 to 900 miles in twelve hours, having at least two well shaped, closed isobars, ellipsoidal or circular (of 0.100 inch of difference). These lows are, of course, not strictly comparable in all respects, as they are of different dimensions, gradients, and ratios of axes, ranging from big circular lows extending from the Rockies to the Atlantic Ocean and from the Gulf up to the Lakes, on the one hand, to lows of long oval isobars on the other: but all are comparable in one respect; they are all primary. Their total number for the period 1893–1902 for five months, November to March, inclusive, amounts to 288. A list of all these, classified according to direction of movement, with a subclassification by months of occurrence, is given in Table 1. For instance (under east-northeast, December), will be found XIII, (November) 2p.01, referring to the cyclone track No. XIII, from 8 p. m. on the 2d of December, 1901, to 8 a. m.