

data for investigations new or old, and inspired by his experience with new enthusiasm alike for the magnificent researches of the great observatory, and for his own humbler work?

Such a career deserved unusual recognition, and received it in a merited degree. Almost all the honors of the scientific world fell to his lot, and the list of these distinctions is too long to detail here. But those who knew him will mourn less the disappearance of the distinguished leader of science than the loss of a warm and loyal friend, one of the kindest and most generous of men.

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PRINCETON UNIVERSITY OBSERVATORY,  
February 6, 1919

### SOME RECENT CONTRIBUTIONS TO THE PHYSICS OF THE AIR<sup>1</sup>

THERE has come to us from ancient times the story of a foolish man who sold his birthright for a mess of pottage, and that story to-day is right applicable to us physicists, except in one important particular—we haven't even got the pottage. No department of learning has a richer birthright than has the department of physics in meteorology—the physics of the air. And yet the few institutions that even profess to teach this subject in any form offer it through the department of geology, or, more frequently still, that omnivorous department which, for want of a better name, is called the department of geography. Statistical meteorology, if such expression will be permitted, or climatology, is of course of great interest alike to the geologist and the geographer and this they should teach and in great measure do teach, but climatology is no more meteorology than de-

scriptive geography, for instance, is geology. Its value is great and unquestioned, but its function, like the function of geography, is merely to describe and not to explain.

Meteorology, on the other hand, is concerned with causes, it is the physics of the air, a vast subject of rapidly growing importance upon which peace and war alike are becoming more and more dependent. Only yesterday we

Heard the heavens fill with shouting, and there  
rained a ghastly dew  
From the nations' airy navies grappling in the central blue;  
and to-day  
Saw the heavens fill with commerce, argosies of  
magic sails,  
Pilots of the purple twilight, dropping down with  
costly bales.

It is, therefore, no longer an opportunity, a shamefully neglected opportunity, that invites, but an imperative duty that commands our leading institutions to add to the various subjects taught, studied and investigated in their departments of physics that eminently valuable and fascinatingly difficult branch of geophysics—the physics of the air.

No doubt the great majority of colleges and universities would find it highly impracticable to add a proper course in meteorology to their present long list of electives. Neither is it practicable nor desirable for all of them to teach anthropology, say, despite its fascination, nor even any whatever of the a-to-z kinds of engineering. But it is insisted with all possible emphasis that if taught at all it be taught right—taught as a branch of physics. It is also insisted that there is a growing need, especially in connection with both the science and the art of aviation, for young men who understand the phenomena of the atmosphere. Nor should it be forgotten that when our army called for men trained in meteorological physics it called in vain—they did not exist. Furthermore, it would be a godsend to our national Weather Bureau if in the future it could secure a larger portion of its personnel from among university gradu-

<sup>1</sup> Address of the vice-president and chairman of Section B—Physics, American Association for the Advancement of Science, Baltimore, December, 1918.

ates highly trained in the subjects with which they have to deal. And, finally, it is insisted that the physics of the air offers many opportunities to the creative scholar, and every university must realize that its paramount duty is the fostering of research and the training of investigators, for in no other way can it meet the growing and compelling demands of a progressive civilization.

It must be admitted, however, that it is not now easy to give a connected course on atmospheric physics, for there is no suitable text and the isolated articles upon which such a course must needs be based are scattered through the journals from Dan to Beersheeba and buried under a babel of tongues. But this is only a difficulty, and not, in the face of imperative needs, an excuse. A far greater and very real difficulty has, it is true, confronted most of us, for, until the last decade, or less, several important lectures in such a course would of necessity have been restricted to the same brevity as characterizes Horrebow's famous chapter on snakes in his "Natural History of Iceland"—there aren't any.

Some of these lectures are still unwritten—tantalizing challenges to the skill of the experimentalist and acumen of the analyst—while others have been at least partially supplied, a few of which it will be interesting to review in what follows.

#### TEMPERATURE OF THE FREE AIR

Although efforts to determine the temperature of the free air by means of thermometers carried by kites were made as early as 1749, the experiments being conducted at Glasgow by Alexander Wilson and his pupil Thomas Melville; and although, beginning with Jeffries in his ascent from London in 1784, balloonists have often carried thermometers on their flights, it was only after the development of self-recording instruments and the sounding balloon—both at the very end of the last century—that the vertical distribution of temperature up to even 7 or 8 kilometers became at all accurately known. As is now known, and as shown in Fig. 1, the average

temperature decreases slowly with elevation near the surface, then more and more rapidly to a maximum at some such considerable altitude as 7 to 9 kilometers, where it roughly approaches the adiabatic rate for dry air of approximately  $1^{\circ}$  C. per 103 meters.

These are the observed facts; but here too, as in the investigations of other physical phenomena, a knowledge of what happens is only so much raw material out of which some one happily may fashion the finished product—why it happens. In this case the why is found in the presence of water vapor in the air, its condensation and the latent heat thus rendered sensible. As air is carried to higher levels by vertical convection it progressively expands against the continuously decreasing pressure, and thereby does work at the expense of its own heat. During the dry stage of this convection, that is, until saturation is attained, the cooling is roughly at the rate of  $1^{\circ}$  C. per 103 meters increase of elevation. Immediately condensation begins, however, latent heat is set free and the rate of cooling with elevation correspondingly decreased. But as the amount of vapor condensed per degree drop in temperature decreases with the temperature, it follows that the latent heat set free and the corresponding check in the rate of cooling with elevation also decreases. Hence the continuous temperature-elevation coordinates of a rising mass of saturated air form a curved line. Furthermore, the curve thus formed approximately coincides with the average temperature-altitude curve of the free air throughout all cloud levels, or from 0.5 kilometer, say, to 9 kilometers, or thereabouts, above sea level. This agreement necessarily occurs more or less closely during every rain and in all deep clouds and, therefore, very frequently. Nor can there often be much departure from it between such occasions for during these intervals the whole of this portion of the atmosphere is, as a rule, simultaneously warmed or cooled, and thus the curve in question usually shifted essentially parallel to itself.

It appears, then, that the average tempera-

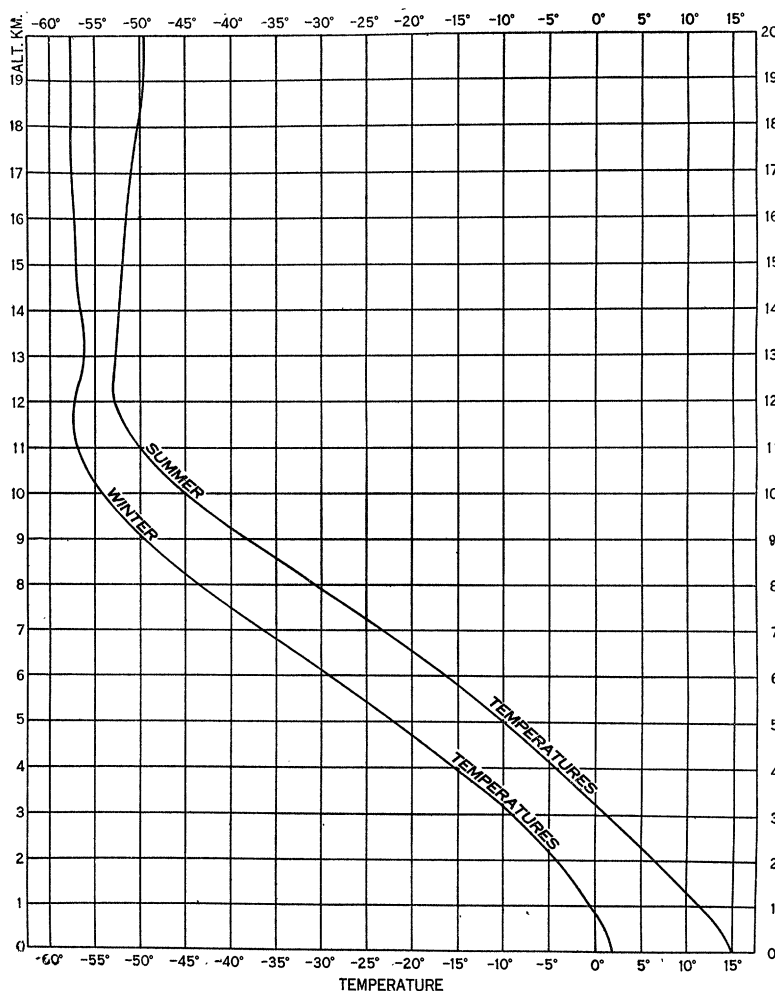


FIG. 1. Temperatures of the air at different elevations.

ture gradient (rate of decrease of temperature with elevation) of the free air is approximately that of a rising mass of saturated air; and for the reasons (a) that frequently the air is rising and saturated, and (b) that departures from the thus established saturation curve develop but slowly, as explained, and are soon eliminated by its reestablishment.

#### THE ISOTHERMAL STATE OF THE UPPER AIR

In April, 1898, Teisserenc de Bort began at Trappes, near Paris, a long series of frequent atmospheric soundings with small balloons carrying automatic registering apparatus.

Among other things, he soon obtained temperature records that indicated the existence either of surprising errors in his apparatus, or of wholly unsuspected conditions in the upper atmosphere. The records generally were tolerably satisfactory up to some 10 to 12 kilometers—satisfactory, because through at least the upper half of this region they showed the temperature to decrease with elevation at, very roughly, the adiabatic rate for dry air. But somewhere in the neighborhood of 11 kilometers elevation everything seemed to go wrong, for from here on the records no

longer indicated a decrease of temperature with increase of elevation, but often even a slight increase! There were but two possible conclusions. Either the apparatus had developed, in actual use, faults that the cross questioning of the laboratory had failed to reveal, or else the upper atmosphere really was in a most unorthodox thermal state. However, numerous records obtained with sounding balloons at different places, by different people and with different apparatus all showed the same thing, namely, that the temperature of the upper atmosphere, though varying slightly from day to day, is, at any given time, substantially the same at all levels, as illustrated by Fig. 1.

Here, then, was a conflict between observational evidence and tradition. Actual measurements had declared the upper atmosphere to be essentially isothermal—declared it in the face of a tradition to the effect that the temperature of the atmosphere must steadily decrease to, or very nearly to, the absolute zero. The name of the joker who first perpetrated this scientific hoax may be lost to fame, but the worst of it is we physicists thoughtlessly perpetuated it. The qualification, thoughtlessly, is used advisedly, for it seems impossible than any process of reasoning could have led to such an erroneous conclusion. If the surface temperature of the earth is maintained, as we know it is, by the absorption of solar radiation, it is equally certain that in turn the temperatures of objects in the full flood of the necessarily equivalent terrestrial radiation can not drop to zero; nor, therefore, can the air, generally, cool by convection to a lower temperature than that which this radiation can maintain. These ideas, so simple that they seem hardly worth expressing, embody the fundamental explanation of why the upper atmosphere is essentially isothermal.

In addition to being exposed all the time to earth radiation the upper air is also exposed much of the time to solar radiation, but there is abundant evidence that the atmosphere at all levels is far more absorptive of

the relatively long wave-length terrestrial radiation than of the much shorter wave-length solar radiation. Hence in computing from *à priori* considerations the probable temperature of the isothermal region, or stratosphere, as it generally is called, it is sufficient, as a first approximation, to consider the effect of only the outgoing radiation, which, according to the work of Abbot and Fowle, of the Smithsonian Institution, is approximately equal in quantity and kind to that which would be emitted by a black surface coincident with the surface of the earth and at the temperature of  $259^{\circ}$  A. As a further simplification the surface in question may be regarded as horizontal and of infinite length and breadth in comparison to any elevation attained by sounding balloons, and, therefore, as giving radiation of equal intensity at all available altitudes.

Now consider two such surfaces, parallel and directly facing each other at a distance apart small in comparison to their width, and having the absolute temperature  $T_2$ , and let an object of any kind whatever be placed at the center of the practically enclosed space. Obviously, according to the laws of radiation, the final temperature of the object in question will also be approximately  $T_2$ . If, now, one of the parallel planes should be removed the uncovered object would be in substantially the same situation, so far as exposure to radiation is concerned, as is the atmosphere of the isothermal region in its exposure to radiation from the lower atmosphere. Of course each particle of the upper air receives some radiation from the adjacent atmosphere, but this is small in comparison to that from lower levels and may, therefore, provisionally be neglected. Hence the problem, as an approximation, is to find the temperature to which an object, assumed infinitesimally small, to fit the case of a gas, will come when exposed to the radiation of a single black plane at a given temperature, and of infinite extent.

But whether an object lies between two planes of equal temperature, as above assumed, or, like the upper air, faces but one,

it clearly is in temperature equilibrium when and only when it loses as much energy by radiation as it gains by absorption. Furthermore, so long as its chemical nature remains the same its coefficient of absorption is but little affected by even considerable changes of temperature. Therefore, whatever the nature of the object, since it is exposed to twice as much radiation when between the two planes as it is when facing but one, it must, in the former case, both absorb and emit twice as much energy as in the latter. That is,

$$E_2 = 2E_1$$

in which  $E_2$  and  $E_1$  are the quantities of heat radiated by the object per second, say, when between two planes and when facing but one, respectively.

Again,

$$E_2 = K_2 T_2^{n_2}$$

and

$$E_1 = K_1 T_1^{n_1}$$

in which  $T_2$  and  $T_1$  are the respective absolute temperatures of the object under the given conditions, and  $K$  and  $n$  its radiation constants.

For every substance there are definite values of  $K$  and  $n$  which, so long as the chemical nature of the object remains the same, do not rapidly vary with change of temperature. Hence, assuming  $K_2 = K_1$  and  $n_2 = n_1$ , it follows, from the above equation

$$E_2 = 2E_1,$$

that

$$T_2 = T_1 \sqrt[n]{2}.$$

From this it appears that there must be some temperature  $T_1$  below which the radiation of the earth and lower atmosphere will not permit the upper atmosphere to cool, though what it is for a given value of  $T_2$  depends upon the value of  $n$ .

But as already explained the value of  $T_2$  is roughly  $259^\circ \text{ A.}$ , and if  $n=4$ , the value for a full radiator, it follows that

$$T_1 = 218^\circ \text{ A.},$$

substantially the value found by observation.

#### STORM EFFECTS ON TEMPERATURE GRADIENTS

Another surprising and, for a time, disconcerting contribution of the sounding balloon to our knowledge of the air relates to the relation of the temperature of the atmosphere to storm conditions. It has long been known that, in general, areas of low pressure—cyclonic areas—are accompanied by inwardly spiralling winds and precipitation; and, conversely, that areas of high pressure—anticyclonic areas—are characterized by outwardly spiralling winds and clear skies. Certainly, then, the inwardly flowing winds of the cyclone must ascend, and the outwardly flowing winds of the anticyclone must be sustained by descending currents. And the next inference, namely, that the air of the cyclone is relatively warm and the air of the anticyclone comparatively cold, seemed equally certain; for, indeed, what else could cause ascent in the one case and descent in the other? But again the facts are not in accord with the simplest and most obvious inference, but just the reverse, through all convective levels, that is, up to the base of the stratosphere, as shown by Figs. 2 and 3, except, in general, near the surface, during the winter. In short, quite contrary to familiar ideas about convection, the ascending air in this case is relatively cold and the descending air comparatively warm. And the stratosphere, as these figures also show, but further confounds this confusion, for here the temperature relations are again reversed, the warmer air being now over cyclones and the colder, above anticyclones.

The facts just stated were, indeed, for a time somewhat disconcerting, but they have helped to the realization that with reference to temperature there are two classes of extratropical cyclones, cold (migratory) and warm (stationary); and also two classes of anticyclones, warm (migratory) and cold (stationary).

That the atmosphere of a stationary anticyclone should average relatively cold, and that of the cyclone comparatively warm, is obvious from the fact that the former occurs only

over cold areas, such as Greenland, Antarctica, etc., and the latter over regions that are warm in comparison with neighboring areas, such as the water southeast of Greenland, the Gulf of Alaska (in the winter), etc. All such cases are readily explained on the principle of thermal convection, and therefore offer nothing new.

thermal origin. Presumably, therefore, their circulations are largely driven and their temperatures in part mechanically determined.

As every one knows, the temperature contrast between the regions of low and high latitudes, respectively, leads to an interzonal circulation of the atmosphere. And because of the rotation of the earth this circulation

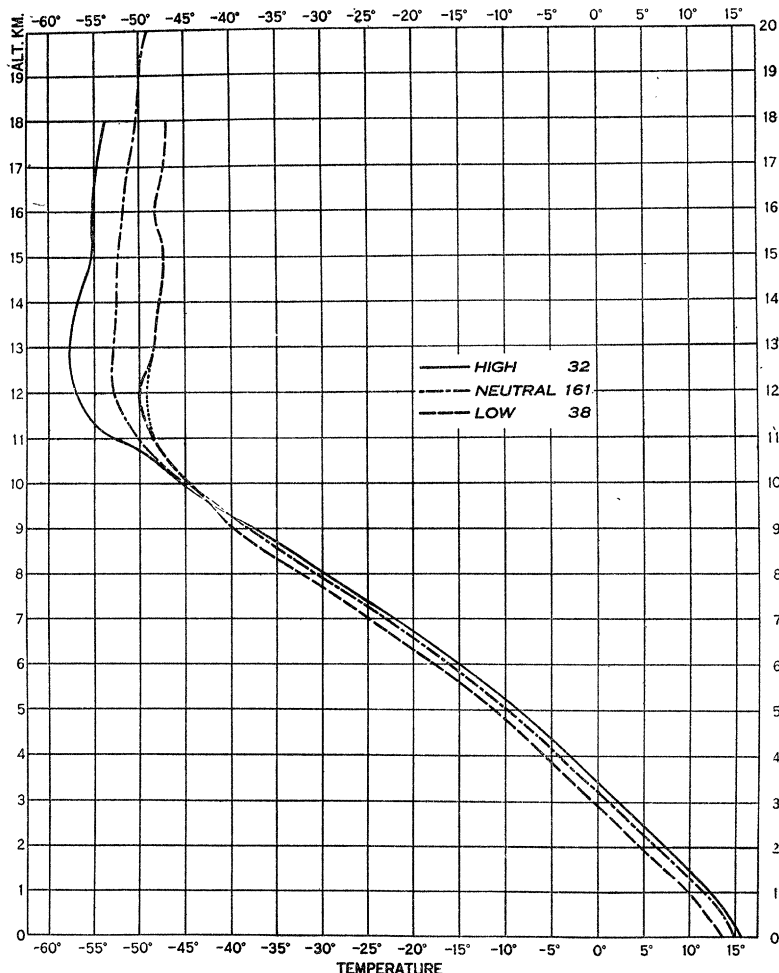


FIG. 2. Relation of summer temperatures to barometric pressure.

The migratory storms, however, at least those of middle latitudes, are quite different. The relation of their temperatures to each other, level for level up to the stratosphere, is just the reverse of that which it would have to be if their circulations were of immediate

becomes, through a portion of its course, the prevailing winds from the west, that up to near the base of the stratosphere average stronger, and are more nearly constant in direction, with increase of altitude. Now, whatever the origin of the migratory anticy-

clone, a subject that still requires further investigation, one of its chief features is deep winds from higher latitudes in its eastern portions. These winds, because of the rotation of the earth, necessarily lose more or less of such west-to-east velocity as they previously

surface up to near the base of the stratosphere. This increase of pressure in turn forces the loaded air to descend, warming on the way according to the adiabatic gradient of  $1^{\circ}$  C. per 103 meters (if free from clouds) and thereby raising the temperature at all levels

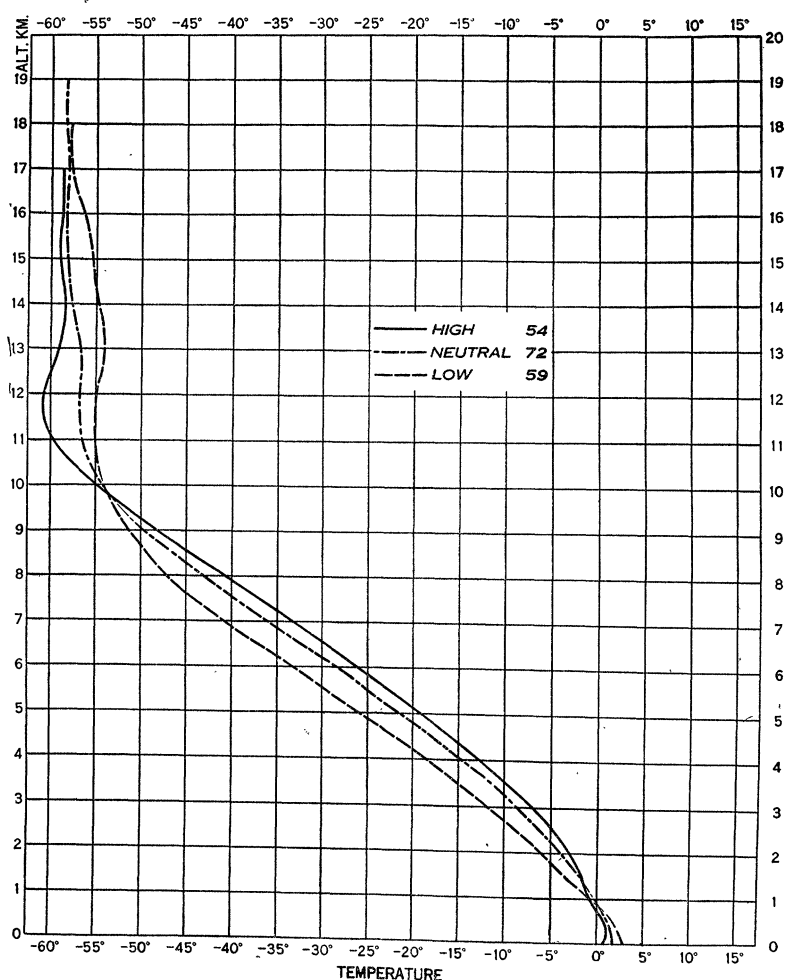


FIG. 3. Relation of winter temperatures to barometric pressure.

may have had. They lag in the midst of the general circulation. Hence the prevailing westerlies flow over them as over a mountain barrier. But by this overflow the westerlies produce at least three different effects: (a) They load the atmosphere over which they pass, and thus increase the pressure from the

through which it passes. (b) They bodily lift the stratosphere whose pressure thereupon tends to decrease at every level in proportion to the initial pressure at that level—a result that would produce dynamically an equal drop in temperature throughout the stratosphere. (c) By their own dynamical cooling, and at

least until the pressure of the upper atmosphere has become readjusted, they establish at the base of the stratosphere a layer of minimum temperature.

These conclusions are in full accord with Figs. 2 and 3.

Similarly, whatever the origin of the migratory cyclone, another of the many meteorological problems that needs further investigation, one of its chief features is a deep wind in its eastern portions from lower to higher latitudes. In this case the rotation of the earth leads to a speeding up of the eastward component of the velocity. Hence this air may be expected to run forward and up and thus to produce a low pressure to its rear. Because of the upward trend thus given to much of the air in the cyclone that portion of it below the stratosphere is more or less dynamically cooled. At the same time the stratosphere bodily drops to lower levels wherever air has been removed from beneath it. Hence its pressure is increased at every level in proportion to the initial pressure at that level and its temperature thereby raised by an equal amount throughout.

Radiation and absorption probably also have some part in determining the temperature conditions and interrelations of migrant cyclones and anticyclones, but the chief cause appears to be purely mechanical, as above explained.

#### THE LAW OF WIND-INCREASE WITH ELEVATION

The fact that wind-velocity generally increases with elevation has long been known, but the law of this increase was not formulated for any levels until only a few years ago, nor the cause back of this law revealed until still more recently. The law in question applies only to that portion of the atmosphere that lies between the elevations of 3 to 4 and 8 to 9 kilometers. Nor could it in any modified form be satisfactorily extended to other levels—not much below 3 kilometers, because of the irregular disturbances due to surface friction, innumerable barriers, and convectional turbulence; nor much beyond 9 kilometers, because not far from this level the vertical temperature gradient, upon which the

winds largely depend, rather abruptly and greatly changes. The form of this law, that applies as a first approximation to so much of the atmosphere, is very simple. It says merely that the velocity of the wind varies inversely with its density, or, in other words, that the mass-flow is a constant. This was determined empirically first by Clayton, of this country, who hid his discovery in a journal of small circulation; and subsequently by Egnell of France, whose proper publication won for the same discovery the appreciative name Egnell's law.

To show the rationale of this law it is convenient to assume the well known fact that the velocity of a steady wind half a kilometer or more above the surface and thus nearly frictionless, is given approximately (neglecting the generally small deflective force due to cyclonic motion) by the equation

$$V = \frac{G}{\rho \omega \sin \phi}$$

in which  $G$  is the horizontal pressure gradient, or difference in pressure per unit distance normal, horizontally, to the local isobar,  $\rho$  the density of the air,  $\omega$  the angular velocity of the earth's rotation and  $\phi$  the latitude. From this equation it follows at once that at any place, the mass-flow,  $\rho v$ , is directly proportional to the horizontal pressure gradient. Hence to find the relation of mass-flow to elevation it is sufficient to determine the relation of horizontal pressure gradient to elevation.

Consider, then, two adjacent columns of air initially exactly alike, and let the temperature of one be increased over that of the other by the same amount throughout. Each isobaric level in the warmed column will thereby be raised in direct proportion to its original height, and the horizontal pressure thus established at each height  $h$  will be proportional to the product of this lift by the local density. That is

$$\frac{G}{G'} = \frac{h\rho}{h'\rho'}$$

But from the height of 3 or 4 kilometers above sea level up to that of 8 or 9, the density of the atmosphere is roughly inversely propor-



tional to the altitude. Hence, to this same crude approximation,  $G$  is also constant through the given range of levels.

Now the actual temperature distributions in the atmosphere at different latitudes are essentially as assumed in the two adjacent columns. Hence the horizontal gradient and therefore the mass-flow,  $\rho v$ , must be roughly constant between the given limiting levels; or, as usually stated, the velocity of the wind inversely proportional to its density.

W. T. HUMPHREYS

(*To be continued*)

### SCIENTIFIC EVENTS

#### MEMORIAL TO LEWIS HENRY MORGAN

TEMPORARILY displayed in Memorial Hall, at the American Museum of Natural History, New York, is a bronze tablet commemorating the one hundredth anniversary of the birth of Lewis Henry Morgan, called the father of American anthropology. The tablet embodies an Iroquois Indian decorative motif and a wampum record of the founding of the "Iroquois League." After being exhibited at the American Museum, the tablet will be sent to Wells College, where it will be permanently installed.

Morgan was born in Aurora, New York, in 1818, and died in 1881 at Rochester. He graduated from Union College in 1840, and was admitted to the New York bar in 1842. In 1855, his interest in certain rich iron deposits led him to make practical explorations into northern Michigan, at that time a wilderness. Here he became interested in the habits and labors of the beaver, and after several years of observation and study wrote his "American Beaver and His Works," which is still considered the most authentic book of its kind.

Early in his life, Mr. Morgan had become a member of a secret society known as the Gordian Knot. This society was accustomed to meet on the ground of the ancient confederacy of the "five nations," holding its council fires at night on the former lands of the Mohawks, Oneidas, Onondages, Cayugas

and Senecas. Gradually its members developed a curiosity about the history, institutions and government of the Indians, and began to gather together odd scraps of information about them. Mr. Morgan's interest became so strong that he devoted himself to serious study of the subject. He wrote a number of papers which were read before the New York Historical Society and elsewhere, and some of which were published in book form in 1851 under the title of "The League of the Iroquois," in which the social organization and government of the confederacy were thoroughly explained, the first scientific account of an Indian tribe. He later wrote a number of books and papers on Indian life, and gathered together a library containing many important works on American ethnology. For the purpose of studying the Six Nations, he organized the Grand Order of the Iroquois. He was assisted in his researches by the Smithsonian Institution and the United States Government.

The tablet at the American Museum was designed by Mr. Gohl, of Auburn. In addition to the symbolic decorations and various facts about Mr. Morgan's life and works inscribed on the tablet, is the following quotation from his "Ancient Society": "Democracy in Government, Brotherhood in Society, Equality in Rights and Privileges and Universal Education foreshadow the Next Higher Plane of Society to Which Experience, Intelligence and Knowledge are Steadily Tending. It will be a Revival in a Higher Form of the Liberty, Equality and Fraternity of the Ancient Gentles."

#### THE BRITISH DYE INDUSTRY<sup>1</sup>

THE works and appliances of the German firms remain substantially undiminished in extent and unimpaired as to organization, while they still possess a large body of expert chemists and engineers fully acquainted with the details of the business, though doubtless there have been serious losses in the course of the war. It is, however, satisfactory to learn from the address of Lord Armaghdale,

<sup>1</sup> From *Nature*.