many times around the tube E in their upward course between the walls of the tubes A and E and are turned over and over in the absorbing solution during the process, thus giving ample opportunity for the removal of the last trace of soluble gases.

This apparatus has been found quite efficient and has given entire satisfaction when applied to the purpose for which it was intended. It is entirely probable that with modifications, in regard to size and minor details, it might find quite general application in various types of work in which the thorough washing or complete absorption of gases is an essential feature.

E. S. STINSON
J. W. SHIVE

LABORATORY OF PLANT PHYSIOLOGY,
NEW JERSEY AGRICULTURAL EXPERIMENT STATION

SPECIAL ARTICLES

AIR-EARTH CURRENTS AND OTHERS

IN SCIENCE of July 27, 1923, pp. 67–68, Dr. L. A. Bauer has criticised my article in SCIENCE of May 25 on the ground that my data was insufficient. I can only reply that I used the data upon which practically all the generalizations upon atmospheric potential gradient have been made. My Figure 1 represented the data from *Observatorio del Ebro* for the six years, 1914–1919, and seems to me to contradict Dr. Bauer's statement that the annual variation of atmospheric potential gradient "does not vary according to the sine of the sun's zenith distance at apparent noon at any given place."

In general, the annual variation which I described in my paper applies to the published data for the following stations besides Tortosa, as may be seen from the table on page 889 of Arrhenius's *Lehrbuch der kosmischen Physik:* Brussels, Kreuznach, St. Louis, Melbourne, Moncalieri, Paris, Ghent, Wolfenbüttel, Helsingfors, Sonnblick, Batavia, Kief and Stuttgart. Arrhenius says that the annual variation at Cape Horn, like that at Melbourne, is opposite to that in the Northern Hemisphere, but I have not seen a tabulation of Cape Horn data. Neither have I seen any data from Helwan, Egypt.[1a]

[1a] In his article on "Atmospheric Electricity," in the Dictionary of Applied Physics, C. T. R. Wilson says: "Such evidence as is available goes to show that the annual variation is of the same character with a maximum in midwinter and a minimum in midsummer throughout middle latitudes in both hemispheres, *i.e.*, everywhere outside the tropics and the polar regions. The records of potential obtained at Helwan (Egypt) are exceptional, showing a maximum in midsummer and a minimum in midwinter."

Also, while Dr. Bauer says the average annual variation of potential gradient varies by but 60 per cent., Arrhenius[1] says the average potential gradient over Europe is about 4.6 times as great in winter as in summer. The same is true for the St. Louis data.

In the article which Dr. Bauer criticized, I called attention to the importance of correcting the observed potential gradient for the conductivity of the air at the time of observation. This was done in the case of the data from Ebro Observatory, but no data on atmospheric conductivity was available for other stations. It was mentioned that this corrected potential gradient is what has usually been defined as an air-earth current. This current, as computed from the atmospheric potential gradient and the atmospheric conductivity amounts, according to Dr. Bauer's estimate,[2] to about 3×10^{-6} ampere per sq. km over the whole earth. This would give a total current of about 1500 amperes continually flowing into the earth, which would raise the electric potential of the earth at the rate of 2,400,000 volts per second. This change in potential, impossible as it seems, fades into insignificance in comparison with that which would accompany some of Dr. Bauer's hypothetical air-earth currents.

My paper of May 25 dealt only with the seasonal variation of atmospheric potential gradient; but there is likewise a diurnal variation of atmospheric potential gradient which must, if the phenomenon is one of induction by a charged earth, vary with the diurnal variation of the earth's potential at the place of observation. For the purpose of showing that such a relation is indicated, I am fortunately able to refer to data which have already been approved by Dr. Bauer. In *Terrestrial Magnetism,* XXV, page 161, Dr. Bauer gives two curves which show what he calls the summer diurnal variation of air-earth current density. One of these curves is there said to represent Dr. Dorno's observations at the Alpine station Davos, and the other is said to represent observations made at the Potsdam Observatory. In Figure 1, below, Dr. Bauer's Davos curve, as scaled from the one in *Terrestrial Magnetism,* is compared with a curve showing the diurnal variation of the electrical potential of the earth at my Palo Alto observatory for the year August, 1920–July, 1921, and in Figure 2, the Potsdam curve is compared with the curve of diurnal variation of earth potential at Palo Alto for the year September, 1921 to August, 1922. In both figures the broken line represents the Palo Alto curves. It will be seen that the air-earth current curves agree with the curves of earth potential variation as closely as they do with each other.

[1] "Kosmische Physik," p. 888.

[2] *Terr. Mag.,* XXV, 156 (Dec., 1920).

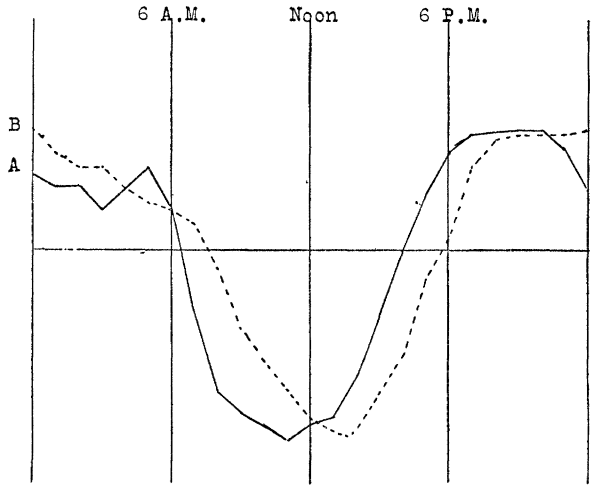

FIGURE 1.—Comparison of diurnal variation of air-earth current at Davos and of the Earth's potential variation at Palo Alto.
A, Air-earth current.
B, Earth-potential variation.

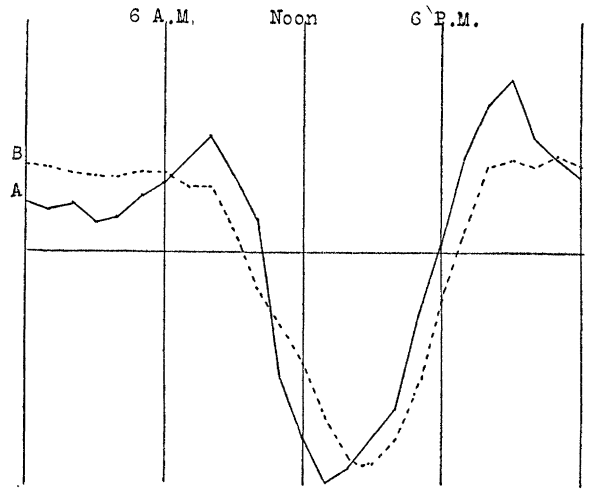

FIGURE 2.—Comparison of diurnal variation of air-earth current at Potsdam and of the Earth's diurnal potential variation at Palo Alto.
A, Air-earth current.
B, Earth-potential variation.

It is true, as Dr. Bauer will probably say, that neither pair of these curves was made at the same time or place; but Dr. Bauer has used the air-earth current curves for comparison with what he calls the diurnal variation of vertical current density of terrestrial magnetism for Cheltenham, Maryland.

And here seems an appropriate place to discuss briefly these vertical currents of terrestrial magnetism which have occupied so conspicuous a place in Dr. Bauer's writings and speeches for the past twenty years.

There have been numerous attempts to analyze the magnetic field of the earth, and to specify a distribution of permanent magnets within the earth or of electric currents flowing around the earth, either above or below its surface, which would give the observed distribution of magnetic force over the earth. None of these attempts has been completely successful, and some of the mathematicians have suggested that the variations from their computed distribution might be due to vertical electric currents flowing into or out of the earth over certain areas. Adolf Schmidt, for example, concluded that to make his analysis agree with observations there would be required vertical currents having an average intensity of 1/6 ampere per sq. km over the whole earth. Since such currents would require an atmospheric potential gradient of some seven and a half million volts per meter, as well as being inconsistent with many other observed phenomena, Schmidt, like his eminent predecessor, Gauss, apparently abandoned all hope of finding an alibi in air-earth currents.[3] Rücker, in England, made a careful computation of the line integrals of magnetic force around areas in the British Isles, where very accurate magnetic data were available, and found no vertical currents flowing into or out of the earth.

In 1904, Dr. Bauer hit upon an original method of locating these hypothetical air-earth currents from magnetic declination charts alone. As a fundamental proposition upon which to base his method, he declares[4] *"A downward electric current, i.e., one passing from the air through the Earth's surface, in accordance with Ampere's rule, will deflect the north end of a magnetic needle to the West."*

Now, as any one who has given any attention to the laws of the deflection of magnets by currents knows, this statement is wholly inconsistent with the facts of observation. In the first place, Ampère's rule says nothing about the points of the compass to which a magnet pole will be deflected by a current. As generally stated, it says that if an observer will regard himself as part of the conductor carrying the current and is so placed that the current will enter at his feet and leave at his head, then a magnetic needle *outside the current* and in front of him will have its north-seeking pole deflected toward his left hand, *no matter in what direction he faces.* In other words, the north-seeking pole of a magnet is driven around a current in clockwise direction as seen by one looking along the current in the direction it is assumed to be flowing. Hence the influence of a vertical current upon a horizontal magnetic needle is indeterminate until the relative positions of the current and magnet are specified.

[3] See Bauer, *Terr. Mag.*, XXV, 146.

[4] *Terr. Mag.*, IX, 123 (Sept., 1904).

A positive current flowing into the earth between the poles of a magnetic needle already oriented by the earth's field would tend to deflect its north end toward the *East,* instead of to the West, as Dr. Bauer's rule states.

Since announcing his discovery, Dr. Bauer has four or five times computed the distribution of vertical electric currents over the earth. In his paper entitled *On Vertical Electric Currents And The Relation Between Terrestrial Magnetism And Atmospheric Electricity,* in *Terrestrial Magnetism,* XXV, pp. 145–162 (Dec., 1920), Dr. Bauer again reiterates his rule of 1904, *viz., "A positive electric current passing, for example, from the air through the Earth's surface, in accordance with Ampere's rule, will deflect the north end of a magnetic needle to the West, a reversed current, on the other hand, would deflect the needle to the East."* Dr. Bauer then computes the line integral of magnetic force around various parallels of latitude, using for his points of computation values scaled from magnetic charts, and not actually measured at the points selected, and then calculates the total vertical current which is flowing into or out of the earth between his selected parallel and the pole, meanwhile apparently forgetting or ignoring the possible currents flowing into or out of the rest of the earth. He then divides the earth into zones of five degrees in width, and gives the total current and the current density for each zone. His conclusions regarding the current density for the different zones are shown in the following table, which is taken from his Table I, p. 151 of his article. The current density is given in amperes per square kilometer. A + sign indicates a current flowing from the earth into the air, *i.e.,* a negative potential gradient over the earth, while the — sign indicates a current flowing into the earth, and consequently a positive atmospheric potential gradient.

Zone	N. Hemisphere	S. Hemisphere
Pole to lat. 50°	+ .021	+ .018
Lat. 50° to lat. 45°	+ .045	+ .034
" 45° " " 40°	— .006	— .047
" 40° " " 35°	+ .018	— .022
" 35° " " 30°	+ .008	— .031
" 30° " " 25°	— .029	+ .019
" 25° " " 20°	— .037	+ .058
" 20° " " 15°	— .019	+ .041
" 15° " " 10°	— .033	— .041
" 10° " " 5°	— .053	+ .014
" 5° " Equator	— .018	+ .009

After deciding upon the magnitudes of the currents in the different zones, Dr. Bauer proceeds to combine the results for corresponding zones north and south of the Equator, although in seven of the nine pairs of zones thus combined the currents in the two zones are of *opposite* signs. This seems to indicate that Dr. Bauer is not even certain in which direction the currents whose magnitudes he gives are actually flowing. It is also noteworthy that while he found only four + zones in the Northern Hemisphere and seven in the Southern Hemisphere, he concludes that the distribution of air-earth currents is the same in the two hemispheres. This would look as if Dr. Bauer determined the distribution of his currents by some other criterion than observation.

The general conclusions of this investigation are summed up in the following words:

> In the polar caps down to about parallel 45°, the resultant vertical currents are on the average upward for positive currents and downward for negative currents, the average current-density being about 24×10^{-3} ampere per sq. km.; in the region of the Earth between 45° N to 45° S, the resultant vertical currents are on the average downward for positive currents and upward for negative currents, the average current-density being about 10×10^{-3} ampere per sq. km.

It will be seen that in drawing this conclusion Dr. Bauer has reversed the observed signs of more than one third of his currents. It seems to the present writer that this is a sufficient commentary on the credibility of the work. It may also be seen that if the averaging process had been carried a little further the total result would have been *nil,* since there an equal number of + and — zones, and the sums of the + and — currents are equal, which seems to show that in observations of this character the law of probabilities still holds.

While it seems impossible to attach much probability to the existence of these currents, it is not without interest to see what would be some of their consequences if they did exist. Since they are, on the average, ten thousand times as strong as the currents deduced from the atmospheric potential gradient and the atmospheric conductivity, they would seem to require a potential gradient ten thousand times as high as observations have shown, that is, more than a million volts per meter. Also, in the regions between latitude 45° and the poles this potential gradient would be in the opposite direction to that which has been observed. On opposite sides of the parallels of 45° there would accordingly be a difference in the atmospheric potential gradients of from two to three million volts per meter. The total current flowing across these parallels would be 3,540,000 amperes. In the Northern Hemisphere the earth-currents would be from south to north, which is opposite to their observed direction.

But it seems needless to discuss these currents further until Dr. Bauer derives them, as he suggests in his last SCIENCE article that he may do, from the motion of the charged earth through the ether.

FERNANDO SANFORD

PALO ALTO, CAL.