While the scales of the pig-fish are much more regular in their features than those of the squeteague, observations of the radii corroborate the evidence obtained in 1912 that the radii are merely fissures to permit greater freedom of body movement.

Dr. H. V. Wilson, of the University of North Carolina, spent the summer in an examination of the collection of Philippine sponges. The collection embraces all the great groups of sponges: *Calcarea, Hexactinellids,* Tetractinellids including *Lithistida, Monaxonida* and *Keratosa.* Sixty-odd packages were examined. These were found to represent twenty-five species, the majority of which are new forms.

Dr. James J. Wolfe, of Trinity College, devoted his investigations primarily to an examination of the Diatomaceæ of Beaufort. Extensive tow-net collections were made at various localities under a variety of conditions. These are to be continued at monthly intervals for one year. By this means it is hoped a thoroughly representative collection will be secured. Mounts have been made of about 200 species and considerable progress has been made in their identification.

The culture of *Padina* sporelings was again carried on—now with special reference to parthenogenesis. Cultures demonstrably parthenogenetic, started in the laboratory, as in the earlier work, were transferred to the sea. Unfortunately these were destroyed by the severe storm of September 3–4, necessitating their repetition before this work can be reported in full.

Mr. Raymond B. Beckwith, of Olivet College, and Mr. Francis Harper, of Cornell University, who were assigned to the director for duty, accompanied the various collecting trips and kept complete records of their observations, devoting special attention to the habits of the fishes of the region.

In addition to his other duties, Mr. Beckwith accompanied the *Fish Hawk* on the various collecting trips and assisted the director on the survey of the off-shore fishing grounds.

In addition to his regular work Mr. Harper took a large series of photographs and a number of autochromes of live flounders to be used in illustrating Dr. Mast's report. He also made numerous observations on the birds of the region. In addition to the incidental observations on field trips for fishes, a few holidays and Sundays were devoted to this work and a list of 87 species recorded. Ten birds were tagged with leg-bands furnished by the American Bird Banding Association. A breeding colony of herons on an island in the vicinity of the laboratory was found on August 9 to contain approximately 350 little blue herons (*Florida cærulæa*), 150 Louisiana herons (*Hydranassa tricolor ruficollis*), 8 black-crowned night herons (*Nycticorax nycticorax nævius*) and 6 American egrets (*Herodias egretta*). The little blue heron is not recorded as a breeding bird of North Carolina in the American Ornithologist's Union List, and this is the first time the American egret is known to have nested in the vicinity since 1899. Tentative arrangements have been made for the protection of the colony next year by a warden of the National Association of Audubon Societies. A number of species of shore birds were studied and photographed during the latter part of the summer.

An artist, Mrs. E. Bennett Decker, of Washington, D. C., was engaged in making the drawings to illustrate the embryological papers of Dr. Kuntz, and a series of drawings of the dermal denticles and teeth of the sharks of the region to accompany the report of the director on this subject.

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WASHINGTON, D. C.,
March 13, 1914

SPECIAL ARTICLES

THE TRANSMISSION OF TERRESTRIAL RADIATION BY THE EARTH'S ATMOSPHERE IN SUMMER AND IN WINTER

AN indirect measurement of the transmission through the earth's atmosphere of those radiations which are emitted by the earth's solid surface may be made by comparing the actual radiation of a surface at the terrestrial temperature toward the sky, with that toward a black body at absolute zero. The latter can not be directly observed, but may be obtained by measuring the radiation toward a black surface of cavernous shape at known temperatures, using Stefan's law. This method has been used in the present research. If no radiation from the earth's surface can penetrate the atmosphere, as in the case when the sky is obscured by thick clouds, then the sky has the same effective temperature as the ground; but according as more or less surface radiation escapes to space through the air, the effective or apparent temperature of the sky diminishes, although never reaching absolute zero, for that would mean complete absence of absorption.

The radiation to the sky, measured either by a bolometer or a thermopile, falls off very slightly as the pointing of the instrument departs from the zenith, but more rapidly near the horizon where, if the blue is of inferior purity, the whitish sky has an effective temperature almost identical with that of the earth's surface. The dulling of the blue of the sky near the horizon is due to the dust and haze of the lower atmosphere.

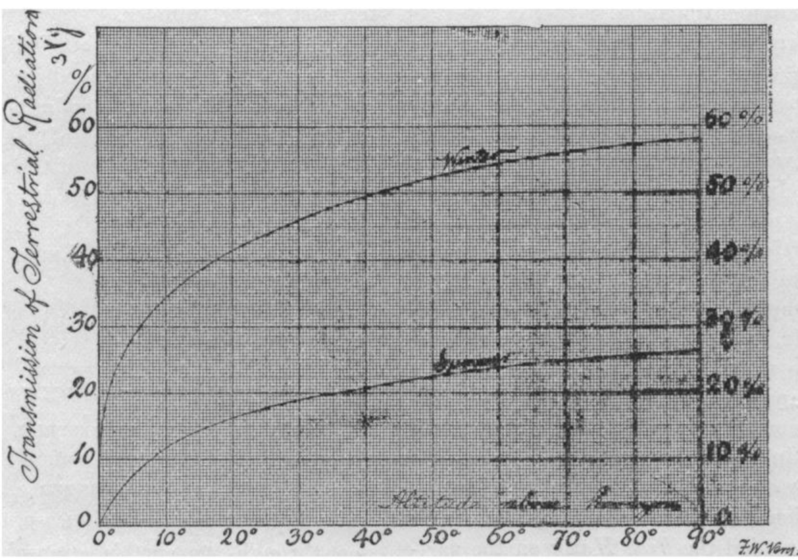

Fig. 1.

its purity much better and a larger transmission, such as that indicated by the upper curve of Fig. 1 (which, however, is meant for a winter curve at sea level) may be given for terrestrial radiation emanating at inclinations with the horizon which are taken as abscissæ, the ordinates being the transmission. In cold winter weather when the ground is covered with snow, atmospheric dust is greatly diminished, and the conditions at sea level approximate to those on mountains. These transmission curves for variously inclined rays have been obtained by dividing the observed sky radiation by the unobstructed radiation to space appropriate to the observed temperature, assuming that space is at the absolute zero of temperature. The lower curve is founded on excellent observations, but the upper one is not so reliable and its shape is partly inferred. The maximum ordinate, however, is sometimes exceeded with the purest skies of winter, and at this season these uniform and deep blue skies are not rare, the difficulty in observing them being usually an instrumental one arising from the necessity

The lower curve of Fig. 1 is derived from observations of sky radiation on a summer's day of good blue sky near sea level. From mountain summits lifted above a large part of the atmospheric dust, the cerulean blue retains of working with exposed instruments. The adopted values of summer transmission, T_S, and of winter transmission, T_W, from which the curves are drawn, are given in the next table:

Altitude Above Horizon	10°	20°	30°	40°	50°	60°	70°	80°	90°
T_S	.116	.162	.190	.208	.226	.238	.249	.256	.262
T_W	.344	.415	.459	.495	.525	.543	.560	.572	.581

Ordinarily when we speak of the transmissivity of the atmosphere without further specification, we mean the vertical transmission through the entire atmosphere. This can be obtained from the zenithal sky radiation, which is all that needs to be considered in what follows.

The transmission of terrestrial radiation by the atmosphere relates entirely to rays of long wave-length, and is effected by processes quite different from those which govern the transmission of solar radiation. Large variations may occur in the transmission of terrestrial radiation, and indeed quite suddenly, so that the eye scarcely appreciates the approach of new atmospheric conditions from any change in the appearance of the sky. It is only rarely that moderately smooth transmission curves can be obtained from the zenith to the horizon, because the conditions are apt to change before the observations can be finished.

The transmission of soil radiation to space is continually fluctuating between zero and an upper limit which seldom exceeds 60 per cent. of the maximum theoretical value for unimpeded radiation. At night, the diurnal convection diminishes greatly, and on land the wind is apt to fall as the sun goes down. Hence on many nights the surface air is approximately calm, and a thin quiescent layer of air forms in contact with the soil, in which the temperature is apt to fall below the dew point as a result of nocturnal radiation. Such a layer of nearly saturated air close to the ground, though exceedingly shallow, develops an extraordinary absorptive power for infra-red radiation in broad diffuse bands as a result of the production of the hydrols, and these bands may eventually extend so widely as to produce practically complete obstruction of terrestrial radiation. An example of this is given in my paper on "Sky Radiation and the Isothermal Layer."[1] After some hours of cooling, further diminution of temperature is prevented in such cases by the obstruction offered by this very thin air layer; and if we compare the loss of radiation from the earth's surface by night and by day, the former is much the smaller on such nights as are here considered. In spite of a phenomenally clear sky, the temperature of the ground as morning approaches often remains almost stationary, partly from the giving up of latent heat of evaporation in the condensation of aqueous vapor, and partly from this increase in the absorptive power of moist air as saturation becomes imminent.[2] If, however, instead of observing the superficial radiation through this closely adherent air layer, we take the radiation from a surface surrounded by relatively dry air in the room of an observatory, and let this radiation pass out through an aperture either directly to the sky, or, as is more convenient, allow the rays to pass to the sky after reflection from a mirror, placed outside the aperture, but far enough above the surface of the ground to be above the layer of adherent soil-chilled air, very little difference is to be found in the transmission of radiation from sources at terrestrial temperatures whether measured by night or by day, such differences as exist being those which may always be expected from changing cloudiness, or from variations in the general conditions as to moisture, etc.

It is common for writers on terrestrial radiation to assume that the earth as a whole radiates at a mean temperature of about

[1] *American Journal of Science*, Vol. XXXV., April, 1913, pp. 377 to 378 and 380 to 381.

[2] Those who are much in the open air know that on frosty mornings in winter a much more comfortable temperature is experienced on passing from the open into woods. The friction of moving air against the innumerable stems of the forest-cover helps to retain the absorbent layers of moist surface air in the woodland, and escape of radiation is impeded. Under exceptional circumstances the excess of temperature in the woodland may reach 20° or 30° C. See G. A. Pearson, "A Meteorological Study of Parks and Timbered Areas in the Western Yellow-pine Forests of Arizona and New Mexico," *Monthly Weather Review*, October, 1913. *Cf.* especially Figs. 6 and 7 (pp. 1620 and 1621).

$+15°$ C., or 288° Abs., or if the temperature regions alone are considered, a temperature of $+10°$ C. $=283°$ Abs. is thought to be better; and this is done by accepting the mean air temperatures observed by meteorologists as if they were those of the soil. Ordinarily, this does no harm for places where the sun shines at a low angle, or where the wind is strong enough to make air and surface temperatures coincide. But when the sun shines at a high angle above the horizon, or in desert regions with light airs, the astrophysicist must know the temperature of the actual radiating surface which becomes far hotter than the air temperature. Even in regions by no means of a desert character, surface layers of fairly dry soil in summer and in the middle of the day may be 20° or 30° C. hotter than the shade temperature of the air as commonly observed; and surfaces of rock in sunshine and on calm days are still hotter. Even plant surfaces in sunshine, though much cooled by evaporation, are appreciably warmer than the air. Taking the currently adopted thermal equivalent of radiation, $\sigma = 7.9 \times 10^{-11} \frac{\text{gram cal.}}{\text{cm.}^2 \text{ min.}}$, a black body at 288° Abs. C. radiates 0.544, and one at 298° radiates 0.623 gram. cal./sq. cm. min. Hence an arid region whose surface is on the average 20° C. hotter than the assigned air temperature during the sunlight hours, will radiate 14.5 per cent. more than the ordinary supposition indicates. On the other hand, most surface material radiates less than a black body (for example, a silicate, such as glass, radiates 93 per cent. as well as lamp black which, in turn, radiates a little less than a truly black body); and since minute accuracy is not attainable, the supposition that the earth agrees with an ideal black radiator may answer as a first approximation.

In summer, the radiation from a black surface at $+25°$ C. to the sky overhead, if the latter be of a deep blue, may be as if to an efficient radiator of the same quality at a temperature of 0° C.

In winter, under similar circumstances the black surface at $-10°$ C. may radiate to a zenithal sky as if to a screen at $-50°$ C., or $-60°$ C.

A mean of three days of good blue sky in winter and of three more in summer follows:

Winter surface temperature ... $=263°.9$ Abs. C.
Summer surface temperature ... $=291°.3$ Abs. C.
Effective temperature of zenithal sky,
Winter $=212°.2$ Abs. C.
Summer $=269°.9$ Abs. C.

By Stefan's law:

	Winter	Summer
Terrestrial radiation (unabsorbed).	.3819	.5685
Radiation from observed zenithal sky.	.1601	.4196
Difference.	.2218	.1489

Transmission (winter) $T_w = .2218/.3819 = .5806$
Transmission (summer) $T_s = .1489/.5685 = .2619$
Transmission (mean of summer and winter) $= .4213$

We may say that a round 40 per cent. is near enough for an approximate estimate of the average transmission of terrestrial radiation from land surfaces in mid latitudes.

In a note in the *Astrophysical Journal* for September, 1913 (p. 198), Mr. Anders Ångström gives 0.15 gram cal./cm.^{2} min. as an average value of the earth's radiation. This agrees very well with the values which I have obtained in summer, but is smaller than the best winter measures, and to such an extent that one would not suppose that Mr. Ångström had ever observed under conditions most favorable to large transmission. He also declares his "belief that the transmission for clear sky seldom is greater than 25 per cent. and seldom is less than about 5 per cent."[3] The stipulation that the sky must be "clear" rules out those imperfect skies affected by a thin cirro stratus veil, which, as will be evident from my article in the *American Journal of Science,* April, 1913, are included within these limits. My observations, which have been made repeatedly, give a fundamentally different result for the best winter skies.

In desert regions, or for hottest, midday and dry summer conditions, it may sometimes be necessary to increase the estimated surface temperatures considerably, as has been shown above; but this does not apply to more than a small part of the earth's surface, and the principal differences between air and soil temperatures, where the soil is considerably hotter than the air, occur during only a part of

[3] *Op. cit.*, p. 200.

the insolation in the middle of the day, and over water surfaces not at all. Taking the earth as a whole, therefore, the adopted estimate of mean surface temperature, as agreeing with the mean local air temperature, can not be altered more than a fraction of a degree by considering the high temperatures of strongly insolated rock and arid soil, because the area occupied by such surfaces is small compared with the vast expanses of ocean, moist soil, and soil protected by vegetation, which are not thus affected.

Mr. Ångström thinks that, of the terrestrial radiation which escapes absorption by the lower layers of the atmosphere, "a considerable part will be absorbed by the ozone in the higher and colder strata of the atmosphere," and he assigns 20 per cent. *of the total remaining radiation* as a probable value of this absorption. Now if we note that the ozone band covers not one tenth of the entire spectrum, and that 20 per cent. would be a fair value for ozone absorption *within the limits of the band* (at least in summer), we may conclude that the absorption which it exerts is nearer to 2 than to 20 per cent. of the entire spectrum. An example will confirm this approximate statement:

On several occasions of strong ozone absorption, the energy in the solar spectrum of wave-length greater than great ≋ (and for our present purpose it makes little difference whether a curve of solar radiation, or one of terrestrial radiation be taken *in this part of the spectrum*) had a mean value of 537 arbitrary units, as measured on a plotting of the spectral energy-curve. On the same scale, the area covered by the ozone band was equal to 17.4 units, or the ozone absorption was 3.24 per cent. of the spectrum lying beyond the center of the greatest of the bands of aqueous vapor. The following separate values show the variability of the band on days of strongest ozone absorption; (*a*) = ozone absorption in the band from 9.1 μ to 10.0 μ as a percentage of the entire unabsorbed energy between 6 μ and 20 μ, (*b*) = ozone absorption of the original unabsorbed energy within the approximate and apparent limits of the band:

Ozone Absorption	(*a*) Per Cent.	(*b*) Per Cent.
Winter measures	3.00	38.8
	3.33	36.9
	3.72	50.0
	3.29	34.5
	3.50	33.3
A single day in July	2.59	21.0
Mean	3.24	35.8

The ozone absorption is considerably smaller in summer than in winter, and ozone probably has its greatest efficiency as a preserver of the earth's heat in the polar regions.

The conditions in my measures of sky radiation were such that the surface temperature could not have differed much from the adopted air temperature, because in winter the sun was low, and in summer the ground was moist; but possibly the values assigned for unobstructed radiation should be lowered to allow for the diminished value of the earth's radiative quality below that of a perfect radiator. This, however, would *increase* the transmission, since the instrument with which the sky radiation was measured was a complete radiator. The thermopile had its very small, blackened, absorbent surface at the center of a hemispherical mirror, 10 cm. in diameter, gold-plated and burnished, the rays entering through a 1 cm. circular, central aperture, entirely open to the outside air. Any rays reflected from the front surface of the thermopile and falling on the mirror, were returned back repeatedly for absorption. In spite of the protection afforded by the case (and by still another, but a wider aperture 2 m. in front of the measuring surface), it was difficult to keep the instrument balanced during very cold or windy weather. Measures were taken in series of five readings. Unless clouds interfered, these readings commonly agreed to the extent indicated in the following examples:

(1) Feb. 2, 1909, $10^{h}20^{m}$ to $10^{h}30^{m}$ A.M. External temperature, +19.°0 F. Dew-point, +13.°5 F. Relative humidity 76.5 per cent. Wind, fresh W.S.W. Sky, milky blue. A few remnants of dissolving strato cumuli low in the east.

(2) Feb. 3, 1909, $9^{h}30^{m}$ to $9^{h}40^{m}$ A.M. Temperature of snow-covered ground (ther-

mometer bulb $\frac{1}{2}$ cm. in snow) $= + 7.°0$ F. External air several degrees warmer. In this case the snow temperature is adopted. Relative humidity, 86 per cent. at 8^h 58^m, 74 per cent. at 10^h 48^m. Hoar frost early A.M. Calm. Good blue sky. Cirro stratus bands S.W. Thin mist in valley below.

(3) Feb. 3, 1909. Evening, 8^h 25^m to 8^h 35^m P.M. External temperature $= + 11.°9$ F. Dew-point, $+ 1.°7$ F. Relative humidity, 65 per cent. Little wind. Sky, quite clear.

(1)	Div. −25.8 (2)	Div. −42.5 (3)	Div. −48.8 (4)
Zenithal sky......	−36.1	−53.0	−35.4
	−28.5	−51.5	−42.3
	−31.9	−48.0	−37.2
	−38.9	−57.1	−44.9
Mean............	−32.2	−50.4	−41.7

Small corrections to the galvanometer readings are needed in order to reduce them to a standard time of vibration.

In summer, the successive readings are apt to agree better, not so much on account of any improvement in the sky, but because the thermal and instrumental conditions are more conducive to accuracy. The following are examples for summer:

July 5, 1909	(4) Early A.M. 7^h 30^m to 7^h 40^m	(5) Noon 11^h 50^m to 12^h
External temperature	+ 66°.7 F.	+ 75°.0 F.
Dew-point	+ 57.	+ 61.
Relative humidity	72%	62%
	Div.	Div.
	— 32.7	— 30.7
Little wind—Deep blue sky.....	— 33.0	— 29.4
Zenithal sky	— 32.7	— 37.1
Galvanometer deflections	— 32.9	— 27.4
	— 30.9	— 32.0
Mean	— 32.4	— 31.3

The loss of heat by radiation from oceanic areas is much smaller than from land, because of the great absorption of this radiation by the very moist air which constantly hangs over the water. The value of 40 per cent. transmission which I have adopted is for land conditions. In ascribing this value to me without any restriction in his "Note on the Transmission of the Atmosphere for Earth Radiation," Mr. Ångström has overlooked a passage in my paper which I will quote:

> In the very moist tropics, nocturnal cooling is only about half as great [as in temperate regions], while over the ocean the total diurnal change of temperature of the water is less than $\frac{1}{2}$° C.

A computation by Lowell's method gave me for the transmission of terrestrial radiation in the tropics this result; that

> whereas about 60 per cent. of surface heat may be emitted as radiation from temperate regions, only one third as much heat escapes in this way in the tropics [over land surfaces]. It is possible that the low value of 10 per cent. . . . may apply to saturated air over the tropical oceans, where the moisture is in an especially absorbent form.[4]

These illustrations will be sufficient to show the very great variability in the coefficient of transmission of terrestrial radiation.

A further statement in Ångström's note, to the effect that

> only a very weak part of this radiation [namely, from the air at 3,000 m. altitude] reaches the earth's surface,

seems to imply that there is supposed to be some interchange of radiation between bodies of air thus widely separated, although actually an air layer only radiates efficiently from a depth of a few meters. The method employed by Mr. Ångström consists in equating one half of the difference of radiation for black bodies at the temperatures found at top and bottom of an air layer 3,000 m. thick, to the absorption in this layer. The result obtained in this way in the lower air depends entirely upon the thickness assumed for the "effective radiating layer." But this layer, as I have shown elsewhere,[5] can not possibly be 3,000 m. deep, nor is it even 1/100 of that depth, as the investigations of Hutchins and Pearson abundantly prove,[6] and the depth of 3,000 meters

[4] *Astrophysical Journal,* Vol. XXXIV., p. 376, December, 1911.

[5] See "Atmospheric Radiation," Bulletin G, U. S. Weather Bureau, where the efficient radiating layer for carbon dioxide is given as 90 cm., and that for illuminating gas hardly exceeds 20 cm. (*Op. cit.*, p. 62.)

[6] *American Journal of Science* (4), Vol. 18, pp. 277–286, October, 1904. For air "some 60 per cent. of its own radiation is absorbed by a column as thin as 245 cm." (*op. cit.*,

appears to have been chosen to suit the hypothesis.[7] In the isothermal layer, by the same principles, there should be negative absorption! Further comment seems unnecessary. I hasten to add that interchange of radiation between *neighboring* air masses is an essential part of radiant progression through the atmosphere.

General Results

I find that with good blue sky there is radiated from a land surface near the middle of the temperate zone something like a thermal equivalent of 0.15 gram cal./sq. cm. min. in summer, and 0.22 gram cal./sq. cm. min. in winter; and these correspond, respectively, to transmissions of 26 and 58 per cent., the mean transmission being 42 per cent., when the sky is quite clear.

In spite of the higher temperature of land surfaces in summer, there is no greater direct outward radiation from these surfaces than in winter, but even a somewhat smaller one, because the radiation has to pass through a more absorbent atmosphere. When the sky is overcast with clouds, direct surface radiation to space ceases, because the seat of action has simply been transferred to the upper surface of the cloud, where a larger proportion of the incoming solar rays is directly reflected back to space, and that which is absorbed is largely transformed into latent heat to reappear elsewhere after complex atmospheric processes. The whole of the absorbed radiation which is manifested as heat in either earth or air must ultimately return to space as radiation. There are many steps in this process, and the return is retarded in general, though variously retarded, or subject to alternate acceleration and retardation.

There is room here for some obscurity, and perhaps difference of opinion, as to what shall be considered a direct return of terrestrial radiation to space. All of the processes of absorption of solar radiation and its conversion into and emission as terrestrial radiation, involve a thermal mechanism and some delay. If it is insisted that the return must be instantaneous, the only "direct" radiation is that which is reflected back to space. But this is not at all what we mean by terrestrial radiation. If, then, we grant that there must be some delay in the return of radiation to space after transformation into long waves, the return being so speedy that it may fairly be called direct, there is really no reason (since we permit a little delay in order that heat may be conducted between various portions of matter) why we may not include in the direct radiation some of that which is due to heat transferred from the surface to the air by convection, and thence, in turn, radiated from the air by the step-by-step process which alone exists in that medium. In fact, by an observer outside the earth in space, this secondarily radiated heat could not readily be distinguished from that emitted after all only a little more directly. When the problem is attacked by purely meteorological methods, we find that these methods increase the computed nocturnal radiation, making it as high as 58.5 per cent. of the total loss of surface heat by radiation and convection combined, according to the method developed by Dr. Percival Lowell in his "Temperature of Mars."[8]

Lowell's equation for nocturnal cooling may be put in the form

$$\frac{T - \Delta T_1}{T - \Delta T_2} = \sqrt[4]{\frac{y(1 - ae)}{y(1 - be)}},$$

where T is the average day temperature on the absolute scale, ΔT_1 is the nocturnal cooling with clear sky, ΔT_2 is the same with cloudy

p. 283). The agreement of the air transmission of 40 per cent. found by these investigators in this laboratory experiment with the value which I have given for the entire atmosphere may be only a coincidence; but the fact remains that there are extensive regions of the spectrum which are not emitted freely by air, and which therefore are not much absorbed by the atmosphere and do not take part in its interchange of radiation.

[7] Certain layers in the atmosphere, which are cloud-laden and at various heights, stop all outgoing radiation and appear as if at the same temperature as the surface, even though they may be 20°, or more, colder, and the difference of temperature bears no relation to the absorption by the intervening air.

[8] *Proc. American Academy of Arts and Sciences*, Vol. XLII., No. 25, March, 1907, p. 660–661.

sky, y is the radiant energy received at the earth's surface, e is the "relative emissivity," or rather, it is the *effective* emissivity from the surface through the air, that is, the radiant emission as affected by atmospheric absorption of rays of long wave-length, and which is governed by the fourth-power Stefan law, but it is distinguished from the convective loss, except in-so-far as these two overlap according to the principle under discussion. The coefficients a and b are numbers derived from the observed transmission of instrumental radiation to the sky applied to the meteorological data under clear, and cloudy, nocturnal conditions, respectively.

The equation rests upon the observed fact that $\Delta T_1 : \Delta T_2 = 5:2$, which holds good for both tropical and temperate regions; also upon the fact that there is no difference between the mean temperature of clear and cloudy days; and the numerical coefficients are chosen on the assumption that the average air transmission is the same for either day or night. This I find to be justified so far as the radiation of the measuring instrument to the sky is concerned, but it does not hold, in general, for the surface of the ground. Hence there arises a discrepancy. For example, if we let $T =$ the mean day temperature, 292° Abs. C., and take the average transmission of instrumental radiation as 40 per cent. for clear sky, we have the effective transmission of a unit of energy with a cloudy sky $= 2/5 \times 0.40 = 0.16$, and the average transmission for day sky, assuming that there are as many clear days as cloudy, is 0.28. The mean transmission for an average day and a clear night becomes

$$a = \tfrac{1}{2}(0.28 + 0.40) = 0.34;$$

and the mean effective transmission for an average day and a cloudy night is

$$b = \tfrac{1}{2}(0.28 + 0.16) = 0.22.$$

For mean temperate values,

$$\frac{T - \Delta T_1}{T - \Delta T_2} = \frac{292 - 10}{292 - 4} = .9792,$$

$$\frac{1 - .34e}{1 - .22e} = (.9792)^4 = .9196,$$

$$e = .585.$$

But this is practically the effective transmission of the earth's radiation, because the emissivity of the earth is nearly that of a black body. Nevertheless, e by the computation is nearly 50 per cent. larger than the transmission of instrumental radiation with which we started, so that, in round numbers, the equation as it stands raises the transmission from .40 to .60, mean $= .50$, which is the value adopted by Lowell. The explanation of the discrepancy between the transmission obtained from measures of sky radiation, and that from nocturnal cooling, appears to lie in the reconversion of a part of the heat abstracted from the surface by convection currents, into radiation which is added to the radiation emitted as such from the ground; but the large part of the energy communicated to the air by convection remains in the circulation of the air so long that it does not affect the diurnal changes on which the equation is based.

A similar computation for the tropics gave the result that e has only about one third of the value derived from measures in the temperate zone, while the discrepancy is very much smaller and has the opposite sign. This may mean that the excessive evaporation and precipitation of the tropics bring thermal losses and gains which still further complicate the relations between radiation and convection. Evidently there may be some ambiguity about the term "terrestrial radiation," unless we limit our definitions very carefully.

As a check upon these measures I have used my determination of the transmission of the proper lunar radiation by the earth's atmosphere in which values as high as 48 per cent. were obtained in winter. The transmission of lunar radiation is relatively smaller than that for terrestrial radiation from a land surface by the same atmosphere, because, owing to the higher temperature of the lunar surface, its radiation invades regions of the spectrum where the atmospheric absorption is especially large.[9]

Frank W. Very
Westwood Astrophysical Observatory,
December, 1913

[9] See F. W. Very, "Sky Radiation and the Isothermal Layer," *American Journal of Science*, Vol. XXXV., p. 379, April, 1913.