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# SCIENCE

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CONTENTS




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## THE SOURCE OF SOLAR ENERGY[1]

### INTRODUCTION

IT has been wisely said by Dr. W. W. Campbell that a scientist does not create the truth. He does nothing whatever to the truth; he simply uncovers it. Through the analysis of physical science, the universe is resolved into atoms—protons and electrons, and the cosmic laws are reduced to action and reaction of these integral parts. A general simplification has resulted; in the terms of atoms many complicated phenomena have been solved, and it is hoped that the new physics will shed some light on the problem in hand—the source of solar energy.

It is known that throughout entire geological time the sun has been radiating energy at a rate which has varied but little. With the generally accepted estimate of the age of the earth[2] each gram of the sun has accounted for about $2 \times 10^9$ calories, and the well-known problem arises: whence came this heat. The great quantity of the solar radiation and the inadequacy of the simpler theories to account for it have been so frequently discussed that a short review of them will suffice here.

It does not come within the scope of this paper to reexamine the data for determining the age of the earth. Estimates have ranged from $10^8$ years to Russell's absolute maximum of $6 \times 10^9$. Since even the minimum value given above is far in excess of that demanded by the following theories it is not necessary for our present purpose to defend any specific value. For the sake of definiteness we adopt the value $10^9$ as of the proper order of magnitude, especially since this figure has apparently met with wider acceptance than any other.

### (1) ORIGINAL HEAT

The sun radiates about two ergs per second, or 1.5 calories per year, for each gram of its mass. The researches of Emden, Eddington, Jeans and others have shown that, in order to maintain the observed mean density of 1.4 against the enormous pressures existing in the far interior, a critical temperature of some 10,000,000° to 30,000,000° K is required. The opacity of the interior, by setting up a negative temperature gradient, reduces the temperature of the photospheric surface approximately to 6,000° K.

[1] Awarded the A. Cressy Morrison Prize in 1926 by the New York Academy of Sciences.

[2] $10^9$ years.

The mechanism of the opacity is generally recognized to be the interaction of radiation and electrons with positive nuclei and highly ionized atoms in the center of the sun.

In spite of the great central temperature, it is immediately obvious that mere cooling is insufficient to account for the supply of the sun's heat. At the observed rate of radiation, and even assuming a maximum value for the specific heat, the lapse of a comparatively short period of time, say a million years, would certainly reduce the temperature so that the surface would be markedly cooler. The customary argument used in this connection is not valid. It has been said that since the average temperature of the sun falls at least one degree a year the surface would be sensibly cooler in even a few thousand years. The reduction of the central temperature by so small a fraction would scarcely disturb the temperature gradient. As far as historical time is concerned, the sun may well have been a hot body cooling according to the well-established laws of heat conduction. But when we take geological time into consideration the case is different. We must find some source of heat to augment the original supply. We shall consider in turn the various possible ways in which the energy may have originated.

### (2) Chemical

Under this heading are grouped the processes which deal with the liberation of heat by the chemical combination of two or more atoms. Combustion is a specific example, governed by the equation:

$$C + 2O = CO_2 + 2140 \text{ cal. per gm. of reacting substance,} \quad (1)$$

which is equivalent to saying that the energy in one gram of uncombined carbon and oxygen, mixed in the proportion of one atom of the former to two of the latter, exceeds that in one gram of carbon dioxide by 2,140 calories. In no case has the heat of any chemical reaction been found to exceed ten times the value in the above equation. In the past billion years each gram of the sun will have radiated $10^5$ times as much heat as could possibly be generated chemically. It is immediately obvious that chemical activity contributes practically nothing to the total energy of the sun.

### (3) Gravitation

(a) *Meteoric.* The discovery, by Rumford (1798) and Davy (1799), that heat has its mechanical equivalent in work, led to other theories regarding the source of solar energy. The first of these was Mayer's hypothesis that the radiation might be continually replenished by an incessant rain of meteoric matter upon the solar surface. It is easily shown that a piece of matter, falling from a great distance, would reach the sun with a velocity of some $6 \times 10^7$ cm./sec. Substituting in the well-known formula for the kinetic energy,

$$E = 1/2\ m\ v^2, \quad (2)$$

and, taking m equal to one gram, we get

$$E = 1.8 \times 10^{15} \text{ ergs} = 3.8 \times 10^7 \text{ calories}, \quad (3)$$

or about 20,000 times the heat produced by the complete combustion of a gram of carbon and oxygen, as shown above. The total annual radiation of about $3 \times 10^{33}$ calories would, then, be equivalent to an influx of $8 \times 10^{25}$ grams of meteors per year or 3.7 grams per square centimeter of surface per day.

Objections to this theory are many and serious. In the first place the density of meteoric matter in space, calculated from the frequency with which meteors are observed to strike the earth, is far too low to furnish even a fraction of the material required by the hypothesis. Furthermore, the increase of solar mass by such a process of accretion would produce corresponding accelerations in the movements of the planets, which could hardly have escaped detection and, finally, it is obvious that the heat produced by impact of solid matter on the solar surface would have a negligible influence on the steep internal temperature gradient. If, by any chance, the sun should happen to encounter during a given year the quantity of meteoric matter mentioned above, the life of the sun would not be lengthened in the least. Instead we would receive, during that year, twice the quantity of heat generally radiated by the sun.

(b) *Contraction.* Of all the theories of the origin of the solar heat, the one which has played the most prominent rôle is that put forth by Helmholtz in 1854. It, too, appeals to gravitation as a source of energy, but instead of the impact of exterior particles, it assumes a general contraction for the sun as a whole to renew the kinetic energy of the solar atoms. It is easily computed that a contraction of but one twentieth in the diameter of the sun per million years would generate enough heat to replenish that lost by radiation. Calculating backwards, we find that if the sun were originally an extended nebula, the average energy produced by contraction to its present state would be 27,000,000 calories per gram. Or, postulating the present rate of radiation as extending uniformly into the past, the minimum age we can derive for the sun, corresponding to an infinite initial radius, would be 18,000,000 years. This would be further reduced by considerations of the greater central density and the necessary discarding of the hypothesis of uniform radiation. The theory of Helmholtz thus fails in the same way as the other theories, in that it does not provide a sufficiently long geological history for the earth. Attractive and ingenious as the hypothesis is, it must, therefore, be discarded.



### (4) Radioactive

Since certain elements which disintegrate with the liberation of enormous quantities of energy have been found, it is necessary to consider what contribution —if any—they make to the total solar radiation. Uranium, for example, undergoes the well-known series of radioactive transformations which finally, after the emission of numerous α, β, and γ rays, terminate in inert radio-lead.

Of the three classes of rays, the alpha variety (which is recognized to consist of helium nuclei ejected with high velocity from the radioactive nucleus), contributes by far the larger percentage of energy. A gram of uranium, in equilibrium with its products, would produce approximately three quarters of a calorie per year, considerably less, therefore, even for a sun made entirely of that element, than would be required to replace the heat lost by radiation.

Examining in turn all radioactive elements, we find that each must be discarded as inadequate. Radium, whose emissive power is about $10^6$ times that of uranium, would be satisfactory only if its "half-life period" were not so short. Since the quantity of radium, however, is halved every 1,730 years, the radiation therefrom would have to vary correspondingly—contrary to observation.

### (5) Intra-atomic

(a) *The Equivalence of Matter and Energy.* We are thus driven by a sort of reductio ad absurdum to consider a principle which has often been suggested on philosophical grounds, *viz.*, the equivalence of matter and energy. The success of the relativity theories, both special and general, render the adoption of this hypothesis less distasteful than it would have been say twenty years ago, and, what is extremely important, they provide a quantitative basis for calculation, according to the well known formulae

$$E = m\ c^2 \quad (4)$$

where m is the mass in grams, c, the velocity of light, and E, the energy to which the given mass is equivalent. Numerically, substituting $m = 1$ and $c = 3 \times 10^{10}$ centimeters per second, we find that one gram of matter equals $9 \times 10^{20}$, or about $2 \times 10^{13}$ calories.

(b) *Chemical and Physical Considerations.* The principle of equivalence has been rendered more probable by its successful application to atomic phenomena, *e.g.*, the fine structure of the spectral lines of hydrogen. Furthermore, the revival of the Prout hypothesis in a somewhat altered form seems to demand it. If 4.032 grams of hydrogen may conceivably be put together in such a way as to make 4.000 grams of helium, we have to postulate the loss of 0.032 grams of mass, or, from the foregoing formula, $6.4 \times 10^{11}$ calories. Writing this in the customary form, we have

$$4\ H = He + 1.6 \times 10^{11} \text{ cal.} \quad (5)$$

calculated, as in equation (1), per gram of reacting material. The above equation signifies that if hydrogen can be transformed into helium, energy of the order of $10^7$ times that produced in an ordinary chemical reaction would be liberated. Herein we find an explanation for the extreme stability of the helium nucleus or α-particle. The most rapidly moving of these have initial velocities of approximately $2 \times 10^9$ centimeters per second. Their kinetic energy,

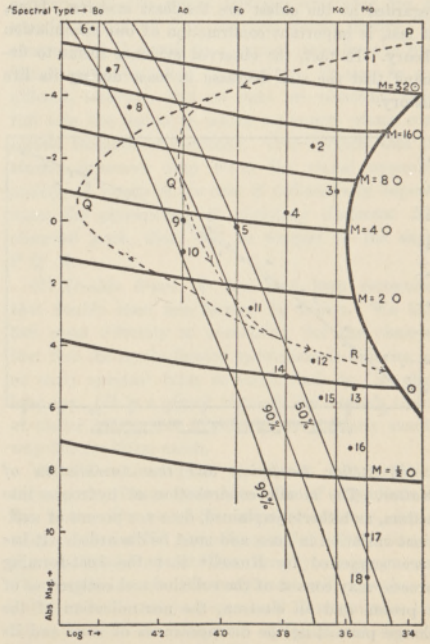



Fig. 1.—The stars, which are those shown by Russell in his diagram in Nature (August 8, 1925), are as follows: 1, Antares; 2, δ Cephei; 3, Arcturus; 4, 5, Capella; 6, Plaskett's star; 7, V Puppis; 8, Y Cygni; 9, β Aurigæ; 10, Sirius; 11, Procyon; 12, 13, α Centauri; 14, Sun; 15, 16, ξ Bootis; 17, 18, Kruger 60.

on a gram basis, from formula (2), equals $5 \times 10^{10}$ calories, or, as will be seen by comparing with equation (5), less than one third the amount necessary to disrupt the nucleus in a collision.

(c) *Stellar Evolution.* Before going further into detail we shall first develop some preliminary considerations. Any theory which applies to the sun must also be applicable to the stars in general and, conversely, it is not improbable that we may find the solution of our problem in a study of stellar statistics. The stages of growth of the present stellar evolutionary theories are so well known that we shall refer to them only briefly. Paramount, was Russell's discovery that the surface temperature and total intrinsic brightness were not entirely independent of one another. Their statistical relationship is shown in the famous giant-dwarf diagram. (See Figs. 1 and 3.)

Eddington's discovery[3] that the luminosity of a star is apparently governed by its mass changed many of our preconceived ideas regarding stellar evolution. His findings are summarized in Fig. 2. It is significant that the stars which we have always regarded as the oldest are the least massive. Here, at last, is important confirmation of our annihilation theory. In fact, the observed evidence seems to demand that the star decrease in mass during its life history.

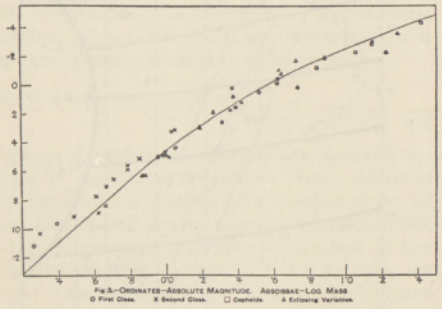


Fig. 2.—Ordinates—Absolute Magnitude. Abscissae—Log Mass
○ First Class. × Second Class. □ Cepheids. △ Eclipsing Variables.

(d) *Stellar Evolution and the Annihilation of Matter.* The atomic condensation of hydrogen into helium, as hitherto explained, does not permit of sufficient variation in mass and must be discarded. It has been suggested by Russell[4] that the heat-forming process may consist of the collision and coalescence of a proton and an electron, the neutralization of the charge permitting the disappearance of mass and its reappearance as energy. This theory, too, has its difficulties, for it would make the transformation dependent upon and favored by high temperature and high pressure. Thus, in the center of the dwarf stars, where we meet with these conditions, the rate of energy production should be greater than in the giant stars, the reverse of the actual case. Eddington has given an excellent summary of the problem.[5]

Jeans's criticism, which applies to any theory making the evolution of energy dependent upon temperature and pressure, is, I think, well founded. The proponents of those theories rely on the adiabatic qualities of the star to maintain equilibrium—*i.e.*, when too much heat is generated they assume an expansion and resultant cooling to "turn off" the supply. It is difficult to see how the star could expand rapidly enough to neutralize the increased rate of production due to the already too rapid emission of energy. Jeans has compared the material to gunpowder and predicts an explosion. Owing to its inertia, the star could hardly compete with the speed of atomic processes.

Eddington attributes the lesser radiation in dwarfs to their greater age, *i.e.*, the transformable material is approaching exhaustion, leaving only the inert elements. He thus apparently agrees with Jeans, who has remarked that ordinary terrestrial atoms, with the exception of the radioactive series, do not show any disposition to be transformed. Furthermore, both Eddington and Russell are extremely indefinite as to their nature of the energy-giving matter. If it is not composed of atoms or their derivatives, what is left? If we need the inert terrestrial type of atoms to dilute the decomposable material, only the radioactive atoms remain to be considered, and radioactivity is a transformation which takes place, as far as we know, almost independently of temperature and pressure. We are led, by a natural process of reasoning, to consider the work of Jeans.

(e) *"Super-Radioactivity."* Jeans has postulated that the energy originates in a sort of super-radioactivity. Eddington's mass-luminosity relation may then be interpreted in a slightly different manner. It has been stated earlier in this paper that the sun radiates 1.5 calories per year per gram of its mass. Among the stars we find that this figure varies considerably from stars like the giant, Canopus, which is generating energy at about five hundred times the solar rate, to dwarfs, like Krueger 60, where the quantity is a hundred times less than the sun or to Sirius B, the white dwarf, which is still smaller by a factor of approximately three.

As far as the radioactive elements go, Jeans points out that we have on our earth a very poor sample

[3] *M.N.* 84 308, 1924.
[4] *Pub. A. S. P.* 31 1, 1919.
[5] *Nat.* 117, May 1, 1926, supplement.



of the universe. The material which comprises our planet came from the outermost layers of the sun, where the generation of energy is already small. If there are, as Jeans postulates,[6] elements of higher atomic weight than uranium, by far the greater amount would, in the absence of convective stirring, sink into the central portion of the sun. It has often been said that there is, apparently, no real reason why such elements should not exist. It is possible, however, that nature has provided a limit. As we pass to the more complex elements we find the nucleus continually increasing and the innermost electronic orbits decreasing in size. Rosseland[7] has pointed out that, for uranium, the radii of the orbit and the nucleus are of the same order of magnitude. He hints that radioactivity may result from the interaction of the two mutual forces. On this theory, radioactivity for elements beyond uranium, where the orbital electrons may actually penetrate the nucleus, would be much greater and it is not impossible that the transformation of matter into energy with the subsequent breaking down into less complex elements would result. By thus assuming that the radiation is liberated independently of temperature and pressure, we avoid the difficulties mentioned in the foregoing sections.

The mutual annihilation of a proton and an electron should result in the birth of a quantum of energy, of wave-length $1.3 \times 10^{-13}$ cm. In the center of a star, this radiation would be transformed into longer wave-lengths by the various forces acting—Compton effect, atomic absorption and emission, scattering, etc. In Nebulae, however, where the opacity is much less, the quanta would escape practically unchanged. The fact that Millikan has recently proved the existence of highly penetrating radiation of approximately this wave-length—the intensity of which is apparently uniform night and day—is important observational proof that some process similar to that which we have described is occurring out in space.

Jeans has shown that the increase in average atomic weight as we near the center of a star, which would be the necessary outcome of the presence of the "super-radioactive" elements, tends to clear away the existing discrepancy in the coefficient of stellar opacity.[8]

Turning again to Fig. 1, which is given by Jeans,[9] we find plotted, in the customary manner, absolute magnitude against spectral type (log T). He employs his equation for stellar equilibrium, assuming a mass and surface temperature for the star in order to compute the absolute magnitude. Curves are drawn, the heavy lines slanting upward toward the left, to represent the stable configurations. When two of the quantities are given, the third may be fixed from the diagram. The curved line on the right marks the boundary between stable and unstable configurations—between positive and negative values of the stellar opacity.

A star whose representative point might fall within this negative region would be radiating energy faster than it could produce it. Equilibrium would now be impossible and the star would draw upon its internal gravitational supply, contracting rapidly. Eddington has shown that, since the gas molecules in the center of the star are free electrons, atomic nuclei and atoms ionized to the innermost orbits, very great densities are permissible. The star would contract until the ionized atoms were packed so tightly together that Boyle's law no longer holds; finally joining that class of stars known as "white dwarfs."

In Fig. 1, the slant lines represent the state of ionization in the stellar interior, calculated for an atomic weight of 20. On the simple theory, the course P Q R would be a typical evolutionary path which might be taken by the star. It may be significant, however, that no stars are observed which fall into the region Q, which represents atoms completely stripped of electrons. This suggests that the atomic processes stop when the nuclei approach nudity, as would be the case if radioactivity depends upon the penetrating of planetary electrons. The observed path, then, will be warped to the shape P Q′ R.

(f) *Double Stars.* It has long been recognized that double stars are formed by fission. We have had some difficulty in accounting for the observed fact that the newly formed spectroscopic binaries are of early spectral type, as established by Campbell, long ago. It is a signal triumph for Jeans's theory of stellar energy that it explains very clearly exactly why this condition exists.

The curves in Fig. 1 are drawn with sufficient accuracy to demonstrate the order of magnitude of the effect. To make the example concrete, let us suppose that a K0 star of mass four times that of the sun breaks up into two exactly similar masses. The brightness of each component will now be one half that of the original star, or 0.75 magnitudes less. Since the absolute magnitude of the parent star was 0.2, we now consult the diagram to determine the equilibrium configuration for a star of the required mass (2 ⊙) and absolute magnitude +1. The figure

[6] Papers in *M.N.*, 1925 and 1926.
[7] *Nature* 111, 357, 1923.
[8] *M.N.* 86, 561, 1926.
[9] *Nat.* 111, 19, 1926.

clearly shows that the stars resulting from the fission would be of spectral type earlier than BO.

The complete theory[10] takes account of the case of unequal fission. Jeans has shown that, in this event, the more massive constituent is to be the brighter and of earlier spectral type, in complete agreement with the observations of Shapley.[11] Reversing the process, we may calculate, from the present condition of the binaries, the state just before the fission occurred. We find that they occupied a position somewhere in the region of the long-period and Cepheid Variables, suggesting that these stars may be binaries in the making.

The realm of visual binaries furnishes additional data which seem to be consistent with the theory of Jeans. The only white dwarf stars known are components of binaries. While this may be attributed to the fact that their dwarf character is emphasized by association with a second star, the theory of energy now under consideration suggests the probability that they are the direct product of extremely unequal division of the heat-producing material.

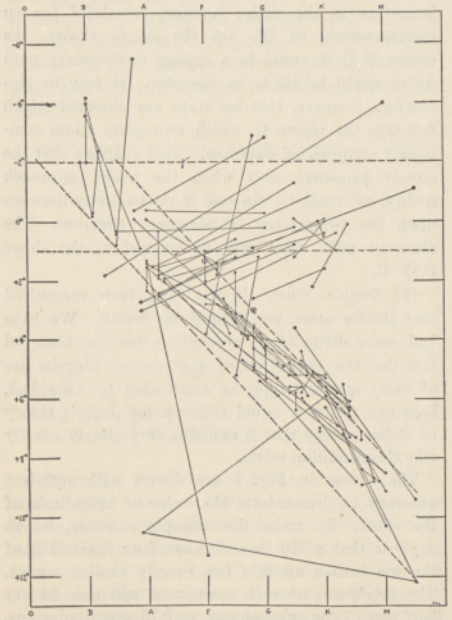


Fig. 3.—Spectral Classes and Absolute Magnitudes of the Components of 85 Visual Binaries.

[10] *M.N.* 85, 800, 1925.

[11] "A Study of the Orbits of Eclipsing Binaries," *Princeton Contributions*, No. 3, 1915.

Hence the splendor of Sirius A and the faintness of Sirius B.

Leonard[12] has investigated the statistics of the visual binaries. From eighty-five double stars of known spectra and parallax, he has plotted the data in the customary manner; the components are connected by a straight line. His diagram is reproduced in Fig. 3. It will be noticed, especially in the giant sequence, that the fainter component is, in general, considerably less bright than the average star of its spectral type. Among the dwarfs the discrepancy is not as marked.

I have examined the visual binaries given in the Harvard list[13] for a similar relationship. Seares[14] has given a curve for the maximum frequency of the stars (not in binaries) for the various spectral types. If the components of a given binary are average stars, the difference in magnitude can be predicted from Seares's curve[15] if their spectral types are known. This difference can be compared with the observed value. Calling the first $\Delta$ m and the second $\Delta$ m′, then $\Delta$ m′–$\Delta$ m will be a measure of the deviation from normality.

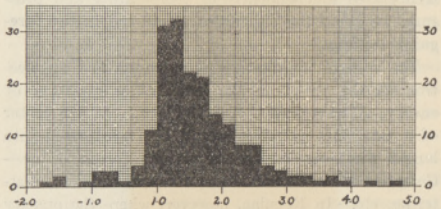



Fig. 4.—Ordinates—Number of Binaries Abscissae—$\Delta$ m′—$\Delta$ m.

The result of the investigation is presented in Fig. 4, which shows the frequency distribution of $\Delta$ m′ – $\Delta$ m for each two tenths of a magnitude. I have excluded from the diagram all optical doubles and binaries where one component was obviously a giant of type earlier than G0 and later than A5. This latter step was necessary in view of the great dispersion of absolute magnitude among the giant F stars. Fig. 4 exhibits a distinct asymmetry, plus values being far in excess of the negative. The result may reasonably be taken to mean that the brighter component of a binary has a higher and the fainter component a lower absolute magnitude than the average stars of their spectral classes. While it is far from proved that all binaries have originated by

[12] *L.O.B.* No. 343, 1923.

[13] *H.A.* 56, No. 7.

[14] *M.W. Contributions* No. 226, 1921.

[15] *Op. cit.* Fig. 1.



fission, it is generally believed that the components have a common origin. The statistical relationship shown in the diagram is interesting, though I do not wish to emphasize any particular interpretation. A similar investigation of the more accurate but less extensive data published in Leonard's paper[16] confirms the preliminary results; the corresponding diagrams differ scarcely at all. The selection of the material is such that extremely faint components, such as Sirius B, are excluded because of the difficulty in securing their spectra. Including these cases would probably tend to increase rather than decrease the observed discrepancy.

On the new intra-atomic theories, the life history of a star is considerably lengthened, to the order of $10^{13}$ years. It has been demonstrated that the orbital diameters and eccentricities of the original spectroscopic binaries could not have changed sufficiently in the short time allowed by the older theories to account for the existence of visual binaries. The new extension of the time scale, however, as Jeans has shown,[17] allows a sufficient number of long-range encounters with other stars to produce the observed result.

(g) *Objections to the Theory of Jeans.* Eddington has criticized Jeans on the grounds that his theory makes the rate of generation independent of the total mass of the star, which is, at first sight, contrary to the observed mass-luminosity relation. The objection, is, however, not well founded, for it is obvious that if we arrange the stars in order of increasing mass we shall find them also arranged approximately in the order of increasing generation of energy per unit mass. One does not necessarily cause the other. They are both the result of the stars having been arranged in order of age. If all the stars at birth had identical masses, they would form statistically some such distribution as the mass-luminosity law. A glance at Fig. 2 will suffice to show that there is sufficient dispersion in the observed stellar luminosities to allow for a wide enough variation in the original mass of a star.

Eddington has further criticized the work of Jeans in the realm of stellar equilibrium. Russell[18] has cleared away the mathematical conflict existing between the theories of these two investigators, showing that neither of their theories is accurate in the strictest sense of the word; the fact, however, that they agree so well with the observed data shows that they are good approximations.

[16] *Op. cit.*

[17] *M.N.* 85, 2, 1924.

[18] *M.N.* 85, 935, 1925.

## Conclusion

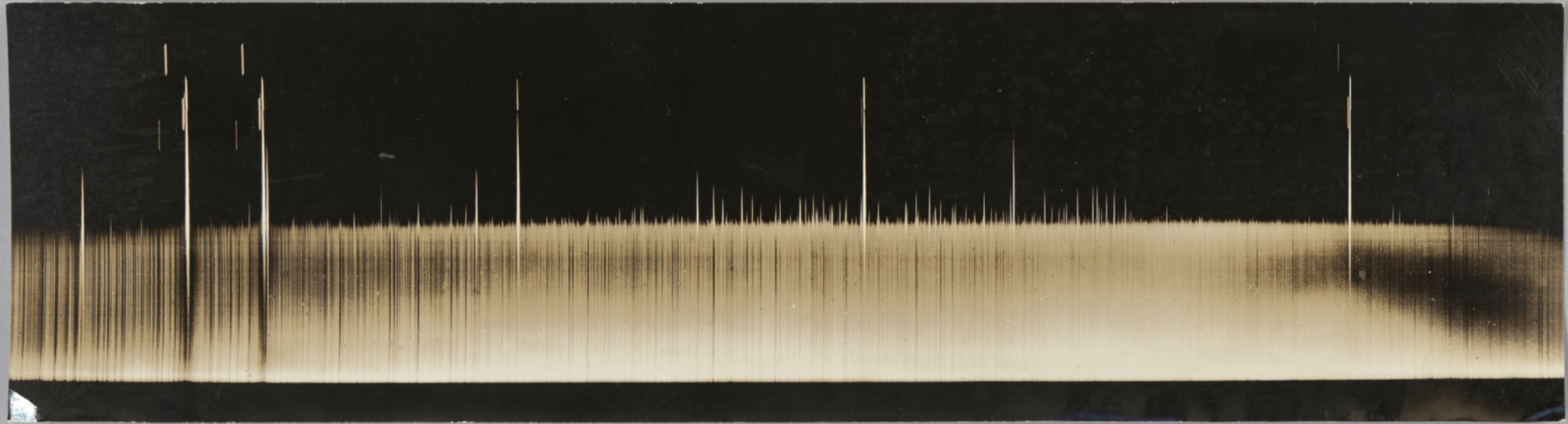
While I have wandered from the main subject of the sun, to consider the source of stellar energy, the two topics are so intimately related that their solutions are identical. I consider that I have demonstrated the reasonableness of Jeans's theory by the manner in which it seems to fit the observed facts. There is, as I can see, no important objection to the hypothesis. It is too much to hope that the foregoing analysis is rigidly complete, but I confidently believe that the main points are established and that further modification will consist in the clearing up of details. The application of astrophysics and atomic theory to a new field appears to have met with considerable success. In spite of this success, however, caution is necessary. The present position of the theory advocated in this paper is somewhat analogous to the place once held by the theory of Helmholtz—*i.e.*, it is the only one sufficiently elastic to stretch over the region of known facts. Our knowledge is yet limited and, with our vision thus impaired, we can not predict the future. Some unforeseen event may upset our present hypothesis as completely as that of Helmholtz; we have built as securely as possible upon observation, and it remains for the future to test the accuracy of this or any other theory so established.

Philosophers may criticize the super-radioactive theory in that it fails to account for the presence of these atoms in the sun and stars. Until now, it seems to have been tacitly assumed that heavier elements were being evolved from lighter ones instead of the reverse process here pictured. This last question, however, is fortunately far enough outside the physical domain to be considered metaphysics. I prefer, then, with Jeans, not to attempt the answer. It is obvious that we must stop before we create something out of nothing.

## Summary

In an attempt to discover a reasonable explanation of the origin and duration of the solar radiation, all possible sources of energy are examined. The following hypotheses are reviewed and discarded, the arguments against their validity being too well known to necessitate a review at this place; (1) Original Heat; (2) Chemical; (3) Gravitational, (a) Meteoric, (b) Contraction; (4) Radioactive.

In view of the failure of the above hypotheses, serious consideration is given to the possible transmutation of matter into energy. Eddington's mass-luminosity relation appears to demand such a process as the general source of stellar radiation. It is shown that any theory which makes the production of energy a function of temperature and pressure is



subject to severe criticisms—(a) the observed rate of energy transformation is greater in the giant than in the hotter and denser dwarf stars; (b) the adiabatic nature of a star would be insufficient to regulate the generation of heat.

Jeans assumes that we have, in the center of stars, a quantity of atoms of atomic weight higher than uranium, whose super-radioactive powers lead to decomposition into energy. The success of the theory in accounting for the following observed facts is enough to demand its serious consideration.

1—Life of stars of order of $10^{13}$ years
2—Better value of the stellar absorption coefficient
3—Giant and dwarf stars
4—White dwarfs
5—Early spectral type of spectroscopic binaries
6—Relations between visual double stars
7—Sufficiently long time for evolution of orbits of visual binaries
8—Cepheid and Long Period Variables (?)

The main objection of Eddington to the theory appears to be invalid.

DONALD H. MENZEL

LICK OBSERVATORY,
Nov. 25, 1926.

## EXUM PERCIVAL LEWIS

IN the death of Exum Percival Lewis on November 17, 1926, there was lost to science an inspiring teacher, a distinguished investigator in spectroscopy and astrophysics, a philosopher and an idealist. Professor Lewis was born in Washington County, North Carolina, on September 15, 1863. He was the son of Henry Exum Lewis, a noted physician, and Emma (Haughton) Lewis. Owing to the privations brought by the Civil War and to the death of his father when he was seven years old his elementary education was obtained entirely at home. As a boy he served as a printer's apprentice and as a young man accepted a position in the War Department at Washington, D. C. While thus employed he attended night classes at Columbian University (now George Washington University) from which he was graduated in 1888 with the degree of B.S. In 1890 he entered the Johns Hopkins University as a graduate student in physics, mathematics and astronomy, and from 1891 to 1895 he was an assistant in physics at that institution, having charge of the laboratory instruction. At the same time, from 1892 to 1895, first as instructor and then as assistant professor, he lectured evenings on general physics, electricity and heat, in the scientific school of Columbian University.

At Johns Hopkins University, under the inspiration of Professor Rowland, Professor Lewis began the work of an investigator in his chosen field of spectroscopy, receiving the degree of Ph.D. in 1895. His thesis, on the infra-red spectra of certain metals, represented practically the first accurate measurements of infra-red lines. His knowledge of astronomy and astrophysics, in addition to his attainments in physics, led, in 1895, to his being called to the University of California, where a physicist was needed who could give proper support to the astronomical work being undertaken on the campus at Berkeley in connection with the work at Lick Observatory. At the University of California he held the position of instructor in physics from 1895 to 1896; assistant professor from 1896 to 1902; associate professor from 1902 to 1908; professor from 1908 to the time of his death, serving after 1918 as the chairman of the department. From 1898 to 1900 he was on leave of absence on a Whiting Fellowship, engaged in spectroscopic research at the University of Berlin, making a systematic investigation of the effects produced by small quantities of other substances in the spectra of nitrogen, hydrogen and oxygen. In this work is found the first recognition of the fact, which has only recently been fully recognized, that the most profound changes in the character and appearance of the spectrum of a given element or substance can be produced by suitably modifying the excitation. It was in connection with this investigation that, in 1900, he discovered the afterglow in a vacuum tube containing nitrogen in which a slight trace of oxygen or water vapor was present. In 1904 he discovered the ability of this afterglow to excite the spectra of various solid substances introduced into the nitrogen-filled tube: this secondary excitation also persisting after the main discharge had ceased. These phenomena, extended by Lord Rayleigh and others, under the term "active nitrogen," have become of great importance. In addition to his researches in active nitrogen he investigated the band spectrum of nitrogen, especially the second positive group in the ultraviolet. His discovery of the effect that the introduction of self-induction in the circuit has on the band spectrum of nitrogen is still one of the most striking examples of what is now known to be the effect of changes in temperature upon any band. Among his other contributions to spectroscopy was the discovery of the continuous spectrum of hydrogen in the ultraviolet, with a determination of its limits and the condition most favorable to its production; the determination of several hundred new lines in the ultraviolet spectra of krypton and xenon; and the ultraviolet spectrum of the solar corona obtained with a quartz spectrograph of his own design. This spectrograph was made possible by a special grant from the Carnegie Institution.



His papers in physics, in other fields than spectroscopy, are numerous and include such subjects as the ionization of gases, conduction of electricity in gases, changes in length and hysteresis losses accompanying magnetization, the mechanism of light emission, the pressure of sound waves and a method of determining amplitudes in sound. His interest in the teaching of physics led him to contribute largely to this subject, through addresses before educational conventions and through publication.

Professor Lewis was strongly attracted to astronomy, especially on the astrophysical side. He was a member of the Crocker Eclipse Expeditions of the Lick Observatory in 1908 at Flint Island in the South Seas, in 1918 at Goldendale, Washington, and in 1923 at Ensenada, Lower California. His special part in these expeditions was the study of the corona. His photographs showed the continuous spectrum of the inner corona from $\lambda 5500$ to $\lambda 3175$, with a number of bright lines, which had not been previously observed, superimposed. His observations led to the conclusion that the temperature of the inner corona probably exceeded 2,000° absolute.

Professor Lewis was a teacher of rare charm. He had the power of separating the essentials from a mass of confusing details and presenting the material with clearness and an absorbing interest. He was sympathetic and patient, allowing great freedom to students and colleagues associated with him, but demanding always a high standard of scholarship. He imparted to the students enthusiasm and high ideals. With many of the present methods of education he was in outspoken opposition, maintaining that they tended to develop mediocrity rather than the highest attainment possible. He was unusually gifted with the power of popular exposition, presenting technical and difficult conceptions in physics and astronomy with a clearness and simplicity that appealed to the layman and brought to his hearers a fuller appreciation of the interest and value of science. Many of these popular addresses, on a wide variety of subjects, were published. They included such titles as "Science, Materialism and Ethics," "The Contribution of Astronomy to Civilization," "The University and the Physical Sciences," "Scientific Imagination," "The Ethical Value of Science," "The Spectroscope, Key to Celestial and Atomic Mysteries," "The Evolution, Death and Resurrection of the Stars."

The geniality of Professor Lewis and his powers of conversation made him a welcomed addition to any intellectual gathering. He was an active member of several clubs, including the Chit Chat Club of San Francisco. He was a member of the American Physical Society, serving as a member of the council, as a member of the editorial board, and as Pacific Coast secretary; the California Academy of Science; the Optical Society of America; the Astronomical Society of the Pacific, serving as a member of the board of directors and as president; the American Association for the Advancement of Science, serving as vice-president, physics section, and as president of the Pacific Division. He was a member of the honor societies Phi Beta Kappa and Sigma Xi.

Professor Lewis was married in 1901 to Louise Sheppard, of San Francisco. His widow, a daughter, Evelyn, and a son, John Sheppard, survive him.

ELMER E. HALL

## SCIENTIFIC EVENTS

### THE BRITISH MOSQUITO CONTROL INSTITUTE

*Nature* prints an account of the first statutory general meeting of the British Mosquito Control Institute, which was held at the Hotel Cecil, London, on March 30. The council was elected in accordance with the articles of association approved by the Board of Trade, and by which the institute is registered under the Companies Acts, 1908–1917, as a company limited by guarantee and not having a share capital. Since the anti-mosquito campaign was begun at Hayling Island about seven years ago, it has become increasingly evident that the work so successfully accomplished there is of more than local interest, and that medical officers of health and sanitary inspectors in many parts of Great Britain, as well as abroad, desire to know how to keep mosquitoes under control. The Ministry of Health can only concern itself with these insects as disease carriers, even though in some districts they make life out of doors almost intolerable in certain months of the year. The Natural History Museum is always willing to identify specimens and give general guidance on methods of dealing with them, but neither it nor the Ministry of Health is concerned with actual field operations by which the mosquito nuisance may be reduced or eliminated. This practical knowledge is, however, available at the British Mosquito Control Institute at Hayling, where there is now a substantial building with laboratory, museum, photographic room and other facilities for the study of all stages of mosquito life and its regulation. The institute has been vested in trustees by the founder and director, Mr. J. F. Marshall, whose devoted services in solving problems of mosquito control are widely known and appreciated. Membership is open to all who are interested in the subject, and it is hoped that, in due course, sufficient support will be forthcoming from members and public bodies to make the institute self-supporting and extend its activities. The council includes among its members

Sir Ronald Ross, Sir William Simpson, Sir Arthur Shipley, Dr. Andrew Balfour, Major E. E. Austen, Sir James Crichton-Browne, Dr. G. A. K. Marshall, Dr. C. M. Wenyon and other entomologists familiar with the mosquito pest, and the chairman is Sir Richard Gregory. The address of the institute is Hayling Island, Hampshire.

## PUBLIC LECTURES AT THE SCHOOL OF TROPICAL MEDICINE OF THE UNIVERSITY OF PORTO RICO

During the present (first) session of the school of tropical medicine of the University of Porto Rico and Columbia University, at San Juan, the following public lectures by visiting scientists were given:

January 11. *The environment:* Professor E. B. Phelps, of the De Lamar Institute of Public Health, Columbia University.

February 4 and 9. *Schistosomiasis, trypanosomiasis, and pulmonary distomatosis in Venezuela:* Dr. Juan Iturbe, Caracas.

February 22 and 25. *Bonds of union between tropical medicine and general medicine, and relationship between Weil's disease and yellow fever:* Dr. A. W. Sellards, associate professor of tropical medicine, Harvard University.

March 2. *Investigations on rickets in New Haven, Conn., and in Porto Rico, with special reference to the effects of sunlight:* Dr. Martha Eliot, of the Children's Bureau, U. S. Department of Labor, and the Yale Medical School.

March 8. *Experimental epidemiology:* Dr. Simon Flexner, director of the Rockefeller Institute for Medical Research, New York.

The last lecture of the series was to be given on May 3 by Dr. James W. Jobling, professor of pathology in Columbia University, on "Blood Destruction with Special Reference to the Influence of Diet."

R. A. Lambert,
*Director*

## THE ONE THOUSANDTH MEETING OF THE ENTOMOLOGICAL SOCIETY OF CORNELL UNIVERSITY

On May 28 there will occur an event of interest to many entomologists in this and in other countries: the one thousandth meeting of Jugatae, the entomological society of Cornell University. The society was founded on February 26, 1897, and has been an important factor in encouraging research in entomology at Cornell throughout its history.

The members of Jugatae are chiefly graduate students in entomology and members of the department. During the thirty years of its existence it has included students from all parts of the world, twenty-six countries having been represented at one time or another. At present there are sixty active members representing Canada, Porto Rico, Chile, Hawaii, the Philippine Islands, Spain, Poland, Australia and China, as well as many of the states of our Union. A full list of prominent entomologists and biologists who have attended meetings would be much too long for presentation here but would include from our own country Dr. L. O. Howard, Dr. W. M. Wheeler, Dr. S. A. Forbes, Dr. Herbert Osborn, Dr. Vernon Kellogg, and from other countries Dr. William Bateson, Dr. Paul Marchal, Dr. Arthur Gibson and Dr. I. J. Tillyard.

Jugatae, though serving as a seminar for the entomological department, has become an institution at Cornell and has achieved a personality not often associated with a seminar. Its object has been "to give all members opportunity to learn of the advanced work being done in the department." Hence more time has been given "to reports of the results of original investigations than to compilations, summaries and reviews." Indeed, the programs of late years have consisted almost exclusively of reports on the research being done by members, and this, perhaps, is the chief reason for the intimacy of the meetings and the place the society holds in the conduct of the department.

The thousandth meeting is to be made the occasion for a celebration to which all its old members have been invited. This celebration will be held on Saturday, May 28, and it is hoped that of its hundreds of former members many will be able to attend.

## THE AMERICAN PHILOSOPHICAL SOCIETY

Dr. F. X. Dercum, emeritus professor of nervous and mental diseases at Jefferson Medical College, has been elected president of the American Philosophical Society to succeed the late Dr. Charles D. Walcott. Dr. Henry Fairfield Osborn, president of the American Museum of Natural History; Dr. William W. Campbell, president of the University of California, and Dr. James A. Breasted, professor of Egyptology and Oriental history at the University of Chicago, have been elected vice-presidents.

Dr. Arthur W. Goodspeed, of the University of Pennsylvania, and Dr. John A. Miller, of Swarthmore College, were named secretaries; Eli K. Price, of Philadelphia, treasurer, and William P. Wilson, of the Philadelphia Museums, curator.

The following councillors were elected to serve for three years: Dr. Edwin Grant Conklin, Princeton; Cyrus Adler and former Governor William C. Sproul, both of Philadelphia, and Charles F. Brush, Cleveland.

Fifteen new members were admitted—Roy Chapman Andrews and Robert Henderson, New York; Arthur P. Davis, Oakland, Calif.; Joseph Erlanger, St. Louis; Irving Fisher and William Lyon Phelps, Yale University; Paul Darwin Foote and Gerrit S. Miller, Jr., U. S. Department of Agriculture, Washington; Tenney Frank, Baltimore; Frank Pierrepont Graves, Albany, N. Y.; B. Smith Hopkins, University of Illinois; Dr. Max L. Margolis, Dr. Thomas Lynch Montgomery, Dr. J. Parsons Schaeffer and Albert S. Weimer, Philadelphia.



## ELECTIONS BY THE NATIONAL ACADEMY OF SCIENCES

Dr. Thomas Hunt Morgan, professor of experimental zoology in Columbia University, was elected president of the National Academy of Sciences at the recent annual meeting held in Washington. Professor Morgan succeeds Professor Albert A. Michelson, of the University of Chicago, for a four-year term. The only other living past president of the academy is Dr. William H. Welch, of the Johns Hopkins University. Dr. Frederick E. Wright, of the Geophysical Laboratory of the Carnegie Institution of Washington, was elected vice-president, in succession to Dr. John C. Merriam, president of the Carnegie Institution. Dr. David White, of the U. S. Geological Survey, was reelected home secretary. As members of the council there were elected Dr. George E. Hale, Dr. John C. Merriam and Dr. J. McKeen Cattell. Members were elected as follows:

Eric Temple Bell, professor of mathematics, California Institute of Technology.

Charles Peter Berkey, professor of geology, Columbia University.

William Bowie, chief of the division of geodesy, U. S. Coast and Geodetic Survey.

Arthur Holly Compton, professor of physics, University of Chicago.

Benjamin Minge Duggar, botanist of the Missouri Botanical Gardens.

Thomas Alva Edison.

Rollins Adams Emerson, professor of plant breeding, Cornell University.

Herbert McLean Evans, professor of anatomy, University of California.

William King Gregory, curator of paleontology, the American Museum of Natural History.

Edwin Powell Hubble, astronomer, Mt. Wilson Observatory.

Claude Silbert Hudson, chemist, U. S. Bureau of Standards.

Alfred Newton Richards, professor of pharmacology, University of Pennsylvania.

Francis Peyton Rous, member of the Rockefeller Institute for Medical Research.

Albert Sauveur, professor of metallurgy, Harvard University.

Henry Van Peters Wilson, professor of zoology, University of North Carolina.

As foreign associates there were elected:

Paul Sabatier, professor of chemistry, University of Toulouse.

Godfrey Harold Hardy, Savillian professor of geometry, University of Oxford.

Carl Stumpf, emeritus professor of philosophy, University of Berlin.

At the meeting of the executive board of the National Research Council of the National Academy, the following general officers were elected: *Chairman,* Gano Dunn, president of the J. G. White Engineering Corporation, New York City; *first vice-chairman,* T. H. Morgan, president-elect of the National Academy of Sciences; *second vice-chairman,* John C. Merriam, president of the Carnegie Institution of Washington; *third vice-chairman,* R. A. Millikan, California Institute of Technology. The permanent secretary, Dr. Vernon Kellogg, and the treasurer, Dr. George K. Burgess, director of the Bureau of Standards, continue in these offices. To replace vacancies occurring in the membership at large of the executive board, James F. Norris, professor of organic chemistry, Massachusetts Institute of Technology; F. R. Moulton, professor of astronomy, University of Chicago, and John R. Freeman, consulting engineer, Providence, were elected.

## SCIENTIFIC NOTES AND NEWS

Dr. Max Weber, emeritus professor of zoology at the University of Amsterdam, an authority on marine mammals and fish and for many years engaged in oceanographic work, has been awarded the Agassiz Medal by the National Academy of Sciences.

Dr. Charles S. Howe, president of the Case School of Applied Science, was awarded the Cleveland Medal for outstanding service in the public interest at the annual banquet of the Cleveland Chamber of Commerce held on April 19. Dr. Howe has been connected continuously with the school for the past thirty-eight years, taking the chair of mathematics and astronomy in 1899. In 1902 he succeeded Dr. Cady Staley as the second president.

Dr. Hideyo Noguchi, of the Rockefeller Institute for Medical Research, has been elected a member of the Royal Academy of Sciences of Denmark.

The medical faculty of Freiburg University has conferred the distinction of doctor *honoris causa* on Tatsukichi Irisawa, professor of internal medicine at Tokyo.

At a meeting of the Medical Society of London, held on March 28, the following were elected honorary

fellows: Professor Irving Cameron (Canada), Professor Sir Charles Sherrington (Oxford), Professor H. C. Jacobaeus (Stockholm), and Professor K. F. Wenckebach (Vienna).

Dr. Konrad E. Birkhaug, assistant professor of bacteriology in the University of Rochester School of Medicine and Dentistry, has been elected a member of the Norwegian Pathological Society in Oslo.

Six American engineers have received the cross of knight of the Czechoslovak Order of the White Lion, "in appreciation of services rendered on behalf of the Czechoslovak State." They are Professor Joseph W. Roe, Calvin W. Rice, Alfred D. Flinn, H. S. Pearson, all of New York; Lawrence W. Wallace, of Washington, and Morris L. Cooke, of Philadelphia.

Professor Cassius J. Keyser, of Columbia University, who asked to be retired on June 30, has been appointed Adrain emeritus professor of mathematics.

The New York Academy of Dentistry recently gave a testimonial dinner to Professor William J. Gies, professor of biochemistry in Columbia University, in recognition of his completion of a survey of the status of dental education in this country on which he worked six years under the auspices of the Carnegie Foundation. At the dinner it was announced that a fellowship fund, to be known as the William J. Gies fellowship fund in biochemistry for dental students at Columbia University, has already received contributions amounting to $18,000.

Dr. Williams McKim Marriott, dean and professor of pediatrics of Washington University School of Medicine, St. Louis, has been elected temporary president of the newly organized Missouri Society for Crippled Children.

The council of the British Illuminating Engineering Society has nominated D. R. Wilson as president for the coming session.

Dr. F. L. Pyman, professor of technological chemistry in the university and in the college of technology, Manchester, has been appointed head of the research laboratories of Messrs. Boots Pure Drug Company, Ltd.

Professor A. E. Taylor, director of the food research institute at Stanford University, has been appointed by President Coolidge a member of the American delegation to the International Economic Conference called by the League of Nations to meet in Geneva on May 4.

Dr. J. C. Drummond, professor of biological chemistry at University College, London, and Dr. E. K. Rideal, lecturer in physical chemistry at the University of Cambridge, are among those who have accepted invitations to take part in the program of the Institute of Chemistry of the American Chemical Society to be held this summer at Pennsylvania State College.

Recent foreign visitors to the United States include Dr. G. Delepine, professor of geology at Lille, France; C. M. F. Swynnerton, chief of the department of game preservation, Tanganyika Territory, Africa, and T. H. C. Taylor, an entomologist on the staff of the Department of Agriculture, Fiji.

*Nature* states that Sir John Russell, director of the Rothamsted Experimental Station; Major Walter Elliot, Parliamentary Under-Secretary of State for Scotland and chairman of the research committee of the Empire Marketing Board, and Dr. J. B. Orr, director of the Rowett Institute for Research in Animal Nutrition, Aberdeen, are on their way to Palestine to inquire into problems of animal husbandry. The delegation will meet delegates from Cyprus and probably also from Iraq.

L. W. Kephart, agronomist in clover investigations, office of forage crops, and R. L. Piemeisel, physiologist of the office of plant geography and physiology, U. S. Bureau of Plant Industry, left Washington on May 1 on a ten-month collecting trip into British East Africa.

Henry B. Collins, Jr., and T. Dale Stewart, of the U. S. National Museum, have left Washington for Alaska to seek for the remains of ancient man and to study contemporary races.

Under the direction of Dr. Max S. Dunn, assistant professor of biochemistry of the University of California, the whaling ship *Lansing* has been cruising off the coast of southern California and Mexico in search of whales, from which the pituitary and some other glands are being preserved for study in laboratories of the university.

Dr. Francis M. Root, associate in medical entomology at the School of Hygiene of the Johns Hopkins University, sailed on April 27 for Venezuela, where he will study the mosquito of the region. He expects to be away until September.

Dr. Walter T. Swingle, in charge of the office of crop physiology and breeding, U. S. Bureau of Plant Industry, sailed for Algeria on April 9, to attend a conference called to discuss baiudh, a destructive disease of dates.

Dr. Lecomte du Nouy, associate member of the Rockefeller Institute for Medical Research, is going to Paris in June on a year's leave. He will continue the work which he has been carrying on on the surface tension and the viscosity of organic and biologic colloids at the Pasteur Institute of Paris.



Professor J. H. Priestley, head of the department of plant pathology of the University of Leeds, England, has returned home after a series of lectures at the University of California.

Dr. T. K. Wolfe, agronomist at the Virginia Agricultural Experiment Station, addressed the University of Virginia chapter of the Society of the Sigma Xi on March 8, on "Achievements in Agricultural Research."

Dr. B. S. Hopkins, professor of inorganic chemistry at the University of Illinois, addressed the Science Club of the Virginia Polytechnic Institute on April 16, on "Some Recent Advancements in Inorganic Chemistry."

It is announced that Professor Kirtley F. Mather, of the department of geology at Harvard University, and the Reverend Dr. John Roach Straton, pastor of Calvary Baptist Church, will engage in debates on the theory of evolution. Tentative dates are May 13 and May 14.

On April 20, 21 and 22 Mr. Austin H. Clark, of the Smithsonian Institution, gave a series of three lectures on "Life in the Sea," at the annual symposium arranged by the Buffalo Society of Natural Sciences, the University of Buffalo and Canisius College. In these lectures marine life was discussed in its relation to life on land, and in its relation to sea life in the past as evidenced by a study of the fossils.

Dr. Charles A. Kraus, research professor of chemistry at Brown University, will offer two lecture courses in the forthcoming summer session at Western Reserve University, June 20 to July 29.

Dr. Nathan Fasten, head of the department of zoology of the Oregon State Agricultural College, gave two addresses before the students and faculty of Willamette University on April 25. In the morning he spoke before a general assembly on "The Social Significance of the Eugenics Movement." In the evening he addressed the men students of the university on "The Physiology of Human Reproduction."

Dr. M. F. Guyer, of the University of Wisconsin, addressed the recent meeting of the Northwestern University chapter of Sigma Xi on the subject of "Heredity and Human Conduct." The meeting was held in the new medical school building on McKinlock Campus.

The Society of Biology in Paris and its affiliated societies, together with the Eighth International Congress of Neurologists, are planning to celebrate the hundredth anniversary of Vulpian's birth from May 27 to June 2, simultaneously with their regular session. It will coincide with the commemoration of the hundredth anniversary of Pinel's death, which is being organized by the Medico-psychologic Society.

A portrait of the late Dr. Henry J. Waters, former dean of the College of Agriculture at the University of Missouri, was recently unveiled in the library of the college of agriculture and presented to the college as the gift of members of the faculty and a number of the alumni.

Yale University plans to honor the memory of two of its teachers, Josiah Willard Gibbs and William Graham Sumner, by the establishment of the Gibbs Fund and the Sumner Fund, $150,000 having been contributed to the $250,000 required for each fund. The income from the Sumner fund will be devoted, according to a vote of the university corporation, to the work of the department of economics, sociology and government; the income from the Gibbs fund to the work of the departments of chemistry, physics and mathematics.

Dr. Irving Bardshar Crandall, a member of the technical staff of the Bell Telephone Laboratories and an authority on the telephonic transmission of speech, died on April 22 at the age of thirty-six years.

Professor Harry Thomas Spengler, of the department of civil engineering at Lafayette College, died on April 23, aged forty-four years.

Dr. Hermann D. Engelhardt, for the past thirty-two years head of the analytical department of Sharp and Dohme, Baltimore, died on February 9, aged sixty-four years.

Dr. Alfred H. Bucherer, professor of mathematical physics at Bonn, Germany, died on April 16, aged sixty-two years. Dr. Bucherer formerly lived in this country when he held the position of chemist for the Aluminum Company of America.

Professor Hermann Ambrown, for many years head of the department of microscopy at Jena, has died at the age of seventy-one years.

The third annual meeting of the Pennsylvania Academy of Science was held at Harrisburg on April 15 and 16. Sixteen papers were read in the scientific program. At the dinner of the academy Dr. George P. Donehoo, of Harrisburg, gave an address on "The Indians of Pennsylvania." The following officers were elected: *President,* E. A. Ziegler, director of the Pennsylvania State School of Forestry; *Vice-president,* F. D. Kern, Pennsylvania State College; *Secretary,* T. L. Guyton, Pennsylvania Bureau of Plant Industry; *Assistant secretary,* M. W. Eddy, Carlisle; *Treasurer,* H. W. Thurston, Pennsylvania State Col-

lege; *Editor,* R. W. Stone, Pennsylvania Geological Survey; *Executive Committee,* O. E. Jennings, University of Pittsburgh; B. L. Miller, Lehigh University; N. H. Stewart, Bucknell University, and W. A. McCubbin, Pennsylvania Bureau of Plant Industry.

Dr. Arnold Dresden, assistant secretary of the American Mathematical Society, reports that the twenty-seventh western meeting of the society was held at the University of Chicago on Friday and Saturday, April 15 and 16, 1927. Professor Virgil Snyder, Cornell University, president of the society, presided at some of the sessions, being relieved by Professor D. R. Curtiss, H. L. Rietz, Dunham Jackson and G. A. Bliss. The total attendance at this meeting was about 120, including 87 members of the society. At this meeting fifty papers on geometry, point set theory, algebra, theory of numbers, applied mathematics and analysis were presented. A special feature was the symposium address on "Some Phases of General Topology," delivered on Friday afternoon by Professor E. W. Chittenden, of the University of Iowa.

The Association of State Geologists on invitation of George Otis Smith, director of the U. S. Geological Survey, met in Washington, D. C., on April 25 and 26, for a conference with officials of the Federal Survey. Sixteen State Geological Surveys were represented. Those present were: H. A. Buehler, Missouri; G. C. Branner, Arkansas; J. A. Bownocker, Ohio; E. F. Bean, Wisconsin; C. N. Gould, Oklahoma; Herman Gunter, Florida; C. A. Hartnagel, New York; M. M. Leighton, Illinois; H. B. Kummel, New Jersey; E. B. Mathews, Maryland; S. W. McCallie, Georgia; R. C. Moore, Kansas; Wilbur A. Nelson, Virginia; W. F. Pond, Tennessee; R. W. Stone, Pennsylvania; I. C. White, West Virginia.

The regular meeting of the Le Conte Geological Club was held at the department of geology, Stanford University, on April 25. Papers were presented by Howell Williams, George E. Ekblaw, M. K. Eliasevich, and Marcel E. Touwaide. Professor A. C. Lawson delivered an after-dinner address on "Geological Observations in Africa." Officers for the coming academic year were elected, Dr. Solon Shedd, curator of the Branner geological library at Stanford, succeeding Mr. E. L. Furlong, of the University of California as president, and Dr. Hubert G. Schenck was reelected secretary-treasurer.

Through the efforts of Dr. I. Maizlish, head of the department of physics at Centenary College, the Sigma Delta chapter of the Sigma Pi Sigma National Physics Fraternity was established on April 20. Dr. J. M. Douglas, head of the department of physics at Davidson College, North Carolina, installed the chapter. Addresses at the initiation banquet were made by President Geo. S. Sexton, Dr. J. M. Douglas, Dr. I. Maizlish, Dean Jno. A. Hardin and Professor Robert Frye. The charter members are: T. J. McCain, *president;* Edwin Monkhouse, *secretary-treasurer;* Henry Fisher, *vice-president,* and John I. McCain. Dr. Maizlish is an honorary member of the Centenary chapter.

Under the auspices of the Associated Business Papers, the American Chemical Society, the American Engineering Council, the American Electrochemical Society, the American Institute of Electrical Engineers, the American Institute of Chemical Engineers, the American Institute of Mining and Metallurgical Engineers, the American Society of Civil Engineers, the American Society of Mechanical Engineers, the Army Ordnance Association and the Society of Automotive Engineers, a special trip to West Point is being arranged on May 12. The *Alexander Hamilton* of the Hudson River Day Line has been chartered for the trip. On reaching West Point the party will be the guests of Brigadier-General M. B. Stewart, superintendent of the academy. A close survey of the operation of the National Military Academy will be permitted and there will be special drills by the cadets, followed by an evening parade in full-dress uniform. It is planned to leave the West 42nd Street pier at 10:00 a. m., returning there at about 10:00 p. m.

*Nature* reports that the tenth Italian Geographical Congress will be held at Milan from September 6 to 15, under the patronage of the King of Italy and the honorary presidency of the prime minister. It is being organized by the Italian Touring Club. There will be five sections: (1) Physical and cartographical; (2) historical; (3) political and economic; (4) explanation; (5) education. At the conclusion of the meetings there will be a number of excursions, by rail or road, to various parts of Italy. During the congress there will be an exhibition of recent Italian maps and photographs.

The fifth exhibition of chemical apparatus and appliances will take place from June 7 to 19 at Essen, Germany, and simultaneously the principal conference of the Association of German Chemists. Previous exhibitions have been held at Hanover, Stuttgart, Hamburg and Nürnberg, under the name of the "Achema." The name "Achema" is a combination of the initial letters of the "Ausstellung für chemisches Apparate-Wesen" (exhibition of chemical apparatus and appliances). Apart from the problems of chemical apparatus technic in general, which arise from science and practice, the matter of apparatus for the chemical treatment of carbon will have special attention. The exhibition will be held in five halls situated on the exhibition grounds at Essen, which have been completely renovated for the purpose.



The opening of the Museums of the Peaceful Arts in New York City took place on April 20, following a dinner meeting of the American members of the Newcomen Society. The Museums of the Peaceful Arts, of which Dr. F. C. Brown was recently appointed director, occupy temporary headquarters at the Scientific American Building, 24 West Fortieth Street, where a start has been made in organizing a great industrial technical museum for the city, made possible by a bequest from the late Henry R. Towne. The Newcomen Society is organized for the study of history and technology. Its headquarters are in London, but it has an active group in America. Charles Penrose, American member of the council, presided at the meeting which followed dinner at the Engineers' Club. This meeting was held simultaneously with a meeting in London, and a paper on Marc Sequin and the invention of the tubular boiler was read at both gatherings. Following the dinner the group adjourned to the museums, where they were greeted by Dr. George F. Kunz, president, and surveyed the exhibits so far collected, which include a portion of the lightning rod which Benjamin Franklin erected on St. Paul's Cathedral.

According to *Nature* a Danish scientific expedition, under the leadership of Professor C. Olufsen, and supported by the Carlsberg fund, is now on its way to Senegal to explore the upper region of the valley of the River Niger, the Upper Volta, and the south part of the Sahara, especially Air (Asben or Agadiz). The expedition, the main purpose of which will be to collect objects of ethnological interest for the Danish Museums, is to return via Zinder and Kano, through Nigeria, to the Guinea Coast, and thence by sea to Dakar. Professor Olufsen will be accompanied by two Danish scientific workers, Oluf Hagerup (botanist) and Harry Madsen (zoologist).

## UNIVERSITY AND EDUCATIONAL NOTES

Union College, Schenectady, dedicated its new physics laboratory on April 30. The exercises were held in the building, which is nearing completion.

The will of the late Dr. Walter B. James includes bequests of $25,000 to Columbia University to the endowment fund of the College of Physicians and Surgeons; $25,000 to the New York Academy of Medicine, and $25,000 to the Trudeau Sanatorium, Saranac Lake.

It was announced, April 9, that Samuel Mather has subscribed $1,000,000 toward the campaign to raise $6,000,000 by the university hospitals of Cleveland for additions to the medical center. Thirteen years ago, Mr. Mather and his associates secured the land for the medical center, and his gifts to its institutions already total millions of dollars.

Promotions announced by Columbia University include the following from the grade of associate professor to full professor: Dr. Albert T. Poffenberger, psychology; Dr. Samuel R. Powers, natural sciences; Dr. William D. Reeve, mathematics; Dr. William E. Caldwell, clinical obstetrics and gynecology; Dr. William W. Herrick, clinical medicine, and James K. Finch, civil engineering.

Dr. Ross V. Patterson, dean of Jefferson Medical College, has been elected to a full professorship in medicine in the college. Other promotions include Dr. C. E. G. Shannon, to be professor of ophthalmology, and Dr. Fred J. Kalteyer, Dr. E. J. G. Beardsley, and Dr. Elmer H. Funk, professors of medicine.

Dr. Sidney S. Negus, professor of organic chemistry at the University of Richmond, has been appointed to a similar position in the Medical College of Virginia, Richmond.

Dr. J. R. Haag, assistant professor of agricultural and biological chemistry at Pennsylvania State College, has been appointed to a position in the Oregon Experiment Station.

Assistant Professor Ethel M. Terry-McCoy has resigned from the staff of the department of chemistry at the University of Chicago.

Dr. Cecil McLaren West has been appointed professor of anatomy in the University College of South Wales, in succession to Professor D. Hepburn, who retires from the beginning of October.

E. Foex, director of the Central Station of Phytopathology, Paris, has been appointed professor of plant pathology at the National Horticultural School.

## DISCUSSION AND CORRESPONDENCE

### NaOH VERSUS $Na_2CO_3$

As a result of recent investigations upon alkali soils in the division of agricultural chemistry of the Arizona Agricultural Experiment Station, it has been shown that very few black alkali soils actually contain sodium carbonate, under field conditions. The alkalinity of such soils is due to the presence of sodium hydroxide, which in turn is derived from the hydrolysis of sodium zeolite.

The erroneous idea that many soils contain excessive amounts of sodium carbonate has arisen from

the fact that, in an analysis for water soluble salts, a high ratio of water to soil has been used. Under these conditions sodium zeolite will be hydrolyzed almost completely, and the alkalinity when calculated to the dry-soil basis may represent a relatively high percentage of sodium carbonate. The hydroxyl ions that are derived from the hydrolysis of sodium zeolite have heretofore been thought to be derived from the hydrolysis of sodium carbonate. When, in making an extract, the ratio of water to soil is gradually reduced, the percentage of hydroxyl ions is also reduced, until at a ratio that represents the optimum moisture content of the soil, few, if any, OH ions are found in the soil solution.

The titration curves for pH values of black alkali soils have been compared with curves made from solutions of known alkalis, and in this way the results of the soil investigation have been confirmed. This work, which has recently appeared as Technical Bulletin 13 of the Arizona Experiment Station, entitled "Sodium Hydroxide rather than Sodium Carbonate the Source of Alkalinity in Black Alkali Soils," by J. F. Breazeale and W. T. McGeorge, has an important bearing upon the reclamation of alkali lands by leaching, the application of gypsum and other correctives and to other practical soil problems.

P. S. Burgess

University of Arizona

## RESPIRATION OF INSECTS

It has been known for a long time that insects breathe by means of openings called spiracles along both sides of the thorax and abdomen. These openings lead to tubes which branch and rebranch and thus spread to all parts of the body. The abdomen pulsates out and in during respiration.

In order to determine whether some of the spiracles were used for inhaling air and others for exhaling, the following experiments with large active grasshoppers were tried.

The first experiment consisted in placing the body of the grasshopper in a vertical position in a glass vessel. Water was then poured into the vessel until the abdomen was immersed in water and the head and thorax were out of water. The grasshopper was left in this position for twenty-four hours. At the end of that time it was taken out and appeared to be none the worse for its experience. During the course of the experiment I noticed that the abdomen continued to move in a normal manner and that air bubbles kept coming out of the abdomen.

The second experiment consisted in taking another grasshopper and reversing its position so that the head and thorax were under water and the abdomen only was out of water. The grasshopper was left in this position for twenty-four hours and during this time air bubbles came out around the thorax and rose to the surface of the water. When the grasshopper was liberated it seemed quite normal.

In the third experiment a grasshopper was placed in a vertical position in water with only the head out of water to see if air entered the body by any openings around the head. Air bubbles left the body and in ten minutes the grasshopper was limp and apparently lifeless.

### Conclusions

These experiments would seem to prove that no special spiracles are used for inhaling and others used for exhaling, but rather that all are alike in this respect, as the abdomen expands air is taken in and as the body contracts the gases are exhaled.

The same thing is probably true of all insects.

D. A. MacKay

Ottawa Collegiate Institute,
Ottawa, Canada

## FOSSIL REMAINS IN THE LOESS OF EASTERN WASHINGTON

In Science, page 477, November 12, 1926, announcement is made by O. W. Freeman of discovery of fossil bones of a mammoth (Elephas primigenius) in loessial deposits in the vicinity of Cheney, Washington.

This is of interest in connection with the study of the origin, distribution and age of the loessial soil-forming materials of eastern Washington, a subject which has been touched upon at intervals in the pages of this publication. It is particularly suggestive as indicating the age of accumulation of these great deposits from which the loessial soils of this region are derived, though widespread redistribution and modification of the soil materials have since taken and are still taking place.

The purpose of this comment is, however, to call attention to the fact that while reported fossils are rare, the writer, with Messrs. A. T. Strahorn and E. J. Carpenter, of the Bureau of Soils, found some large fossil bones embedded in loessial deposits exposed by a fresh highway cut in September, 1923. The remains were found about thirty miles northeast of Pasco on the Pasco-Kahlotus highway. They were partially removed during the following day under direction of Dr. Kirk Bryan, of the U. S. Geological Survey, and identified as a fossil elephant, and include thigh and pelvic bones, a number of ribs, vertebrae and the lower jaw. These fossil remains are now in the U. S. National Museum at Washington. The upper jaw and skull, however, which now appear essential to complete identification and restoration, were not recovered.



The bones were found on a hill slope bordering a small stream valley. They were embedded in fine-textured, uniform, very fine sandy and silty material of light brown color, without stratification, and entirely free from gravel or coarse gritty materials.

Accompanying the larger fossil bones were a number of jaws, skulls and small bones of small rodent or rodent-like animals, and there was some evidence in teeth marks on some of the rib bones that at least some of these smaller animals were of contemporary date.

A more accurate and exhaustive account of the fossil remains has recently been published by Dr. Bryan.[1]

Macy H. Lapham

Bureau of Soils,
Berkeley, California

## DEFEAT OF ANTI-EVOLUTION IN MINNESOTA

Since Minneapolis, Minnesota, is the home of the Reverend W. B. Riley, a leader in anti-evolution agitation and in attempts at legislation against the teaching of evolution in tax-supported schools in many states, a little more than ordinary interest may be felt by scientific men in the failure of the "Riley bill" before the Minnesota legislature that is now in session. This may be especially so because a letter by the Reverend Riley in a leading newspaper here now admits his defeat, but with so much apparent cheerfulness that a person who knows him well may be inclined to wonder as to just what he expected to accomplish by this bill and whether after all his defeat is not more in appearance than in reality.

It may be well for the evolutionists not to be deceived. The bill as it was presented to the legislature is any way more of a gesture or oratorical skirmish than an effectual attack on evolution teaching. Something more serious for Minnesota may lie behind it. In Minnesota, where the function of the university is defined in the constitution of the state, a mere legislative enactment very probably could in no way bind the university as to its educational policy. It is virtually a fourth department of the state and coordinate with the executive, the legislative and the judicial functions.

The State University has little if anything to fear from direct legislation against teaching any subject whatever in Minnesota. Again it is notable that the Riley bill does not aim broadly to forbid the teaching of evolution, but is specifically directed against the doctrine of the descent of man from animals, as if a particular department of the university is criticised. Against this bill, however, other universities of this state join with the State University in common. Both sides of the controversy thus make a great showing of political strength before the legislature.

Arguments used by either side are not such as are used *pro* and *con* in a scientific debate on the validity of natural science theories of evolution. No scientist as such appears against the bill nor for it. The battle is political when not theologic. Dogmatic assumption and deduction and even gross bigotry are met in kind largely. As a geologist, I could view the whole matter as in the clouds above me. I am spectator only.

Very obviously the Reverend Riley's opponents who do not know him intimately are deceived in him. From occasional contact with him for thirty years, it is not consistent for me to say that there is anything shallow about him. He doubtless has a very deep and serious purpose from which he may not be easily diverted. It may be a very pertinent matter to pause to consider just now as to whether any advantages are losing to the Riley attack.

To the best of my knowledge, the legislature and the governor do not commit themselves in the essential matter in laying aside this bill. Nothing is built up that hinders further agitation. The most sanguine of my friends predict only a lull of a year or two or even four, in Minnesota, whereas a few years ago any such attack at all would have been taken as highly improbable. Anti-evolution may be gaining in public respectability.

As a scientist, I am aware that something new is happening in this controversy about the teaching of evolution in Minnesota's schools. Attack by anti-evolutionists is not new here, however. Attack from the pulpit and otherwise by the Reverend Riley as against individual teachers of sciences began some 20 years ago. An effective method then is to back him off the board in defense of natural science theories of evolution by a plain show of visible evidence in their support. My personal experience is then that he can be a very reasonable and gentlemanly antagonist when faced in that way.

The new thing in the present instance, however, is not only his open attack on whole universities here, but further that the old effective method of meeting him can not be used by anybody. The controversy is gone beyond the field of the natural sciences, dogmatically into theology and politics on both sides. In all this controversy in Minnesota now the science professor is only an innocent bystander, in a sort of a no-man's-land. And, the end is not yet!

Frederick W. Sardeson

Minneapolis, Minn.

[1] U. S. Geol. Survey, Bull. 790–B, The "Palouse Soil" Problem with an account of Elephant Remains in Wind-Borne Soil on the Columbia Plateau of Washington.

## MORE HUMAN TAILS

A few days ago I received a letter from Dr. E. G. Hastings, of the Department of Agricultural Bacteriology of the University of Wisconsin, in which he called my attention to a paper in the collected works of Robert Koch, the second volume, second part, page 822.

On consulting this paper (a most unexpected place for such a revelation), I found two photographs of human beings with well-developed tails about as long as a human foot, which had been photographed by Koch in India in 1871. One was a lad seventeen years old, and the other a child.

I thought that your readers might be interested in these photographs, as Dr. Hastings referred to my note on this subject, which was published in Science in the issue of June 11, 1926.

W. W. Keen

## SCIENTIFIC BOOKS

*The Differential Calorimeter, with Special Reference to the Determination of the Human Basal Metabolism.* By A. K. Noyons. Louvain, 1927. 189 pp., 34 illustrations.

Du Bois's splendid book on basal metabolism,[1] backed by his unique experimental experience, has brought metabolism and, specifically, clinical calorimetry to the attention of physicists and physiologists, as well as medical men. From Louvain, Belgium, there has just appeared a book which not only supplements the technical portion of Du Bois's book but is all the more remarkable when one thinks of its birthplace, and how under most harassing economical conditions the human calorimeter has been developed to a point heretofore never attained. Recognizing that with man all measurements of the heat production, including the heat of vaporization of water, are best made by the differential principle, Professor A. K. Noyons, of the department of physiology of the University of Louvain, has printed in readable English the first description of an extremely clever device which physiologists have long known was being developed at Louvain. This differential calorimeter is unique in that the author, at once a physician, physiologist and physicist, has combined in it the most scientific and accurate methods applicable to the measurement of the heat given off by a human. The compensation chamber furnishes, for the first time, an exact duplicate of the heat of vaporization of water in that precisely the same amount of water vaporized from the skin and lungs of the human subject is there vaporized, and an electrical current, passed through a suitable resistance, generates precisely that amount of heat given off by radiation, convection and conduction from the subject.

Without governmental or, indeed, institutional subvention these calorimeters have been privately constructed and tested, and already one is being prepared for introduction into a large clinic. The technical details may not be discussed here. Noyons has seemingly forestalled every criticism so far as the physics of heat measurement on a human being is concerned—save for the perplexing question as to the changes in the average body temperature. The complete isolation of the patient in a rather somber chamber may be impracticable for temperamental cases. One can but wish that, in addition to the many text references, the extensive literature survey (which is international to a refreshing degree) necessarily made by the author could have been recorded as a list of titles on direct and indirect calorimetry.

The use of English was, we believe, wise. When one knows, as does the reviewer, that the book was thought out in Dutch, written in French, and then translated into English, one is surprised that so few distinctly foreign (though rarely, if ever, obscure) phrases occur.

As a promise of what this new metabolism center is to give us in the future, the book is most stimulating to all who have anything to do with heat production and basal metabolism, and with the present wave of interest in this subject, in perhaps less than a decade we shall all have basal metabolism measurements included as a part of our annual assessment of physical fitness.

Francis G. Benedict
Nutrition Laboratory of the
Carnegie Institution of Washington,
Boston, Massachusetts

[1] Du Bois, E. F. "Basal Metabolism in Health and Disease." Philadelphia, 2d ed., 1927.

## SPECIAL ARTICLES

### PRESSURE PHENOMENA OF THE ELECTRIC WIND[1]

1. *Apparatus.* The spectacular group of experiments which we used to perform once a year seem but rarely to have come to any useful maturity. I can recall only the electronic measurements of Professor Chattock. Having appropriate apparatus at hand, it seemed promising to look at them in detail and in the attached figures I will summarize the main results.

The simple apparatus as originally used (Fig. 4, insert) consisted of the two brass posts $P$, $P'$, usually 8 cm apart and fixed in the hard (or soft) rubber base $B$. $T$ supported by $P$ is a small thimble of brass perforated by the slender tube $U$, which leads to the interferometer U-gauge. The post $P'$ carries the darning needle $n$ coaxially with $U$, and both $n$ and $U$ fit snugly, so that they may be slid to different distances $x$ apart. $P$ and $P'$ are in contact with the poles of a small Wimshurst machine, capable of delivering inch sparks. The latter was usually turned by hand near a clock beating quarter seconds, and the speed of rotation of six turns (sometimes three turns) per second for each plate was easily maintained.

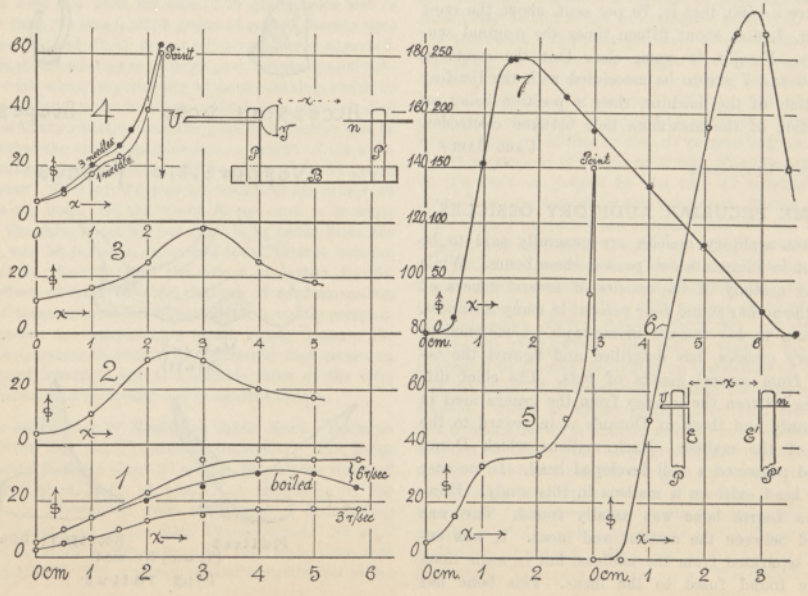
[1] Advance note from a Report to the Carnegie Institution, of Washington, D. C.



2. *Needle electrode.* The group of curves 1 refers to a hard rubber base with posts $P$, $P'$, 8 cm apart. Irregularities are referable to freakish action of the machine quite apart from rotation; but it is noticeable that the pressures ($s$, approximately in $10^{-6}$ atmosphere) are (here) roughly double for 6 rot./sec. as compared with 3 rot./sec. I was disappointed at the relatively low mean pressures in evidence and therefore scraped and boiled the hard rubber base in dilute acid, for greater insulation. The resulting graph actually shows reduced sensitivity and now suggests a maximum. In curve 2 a soft rubber base was tested. The graph is smoother with a very definite crest, but no better in $s$. Finally the graph 3 on a cylindrical hard rubber base is no advance on the others.

Improved conditions appear with graph 4, referring to posts $P$ $P'$ but 4.5 cm apart. Whether one or three sharp needles are used is relatively unimportant; but this graph is rapidly accelerated upward as the needle point approaches the post $P'$. Close inspection of the data convinced me that the graph essentially consists of two constituents, one of which tends to a low crest as heretofore, while the other begins at the maximum and runs with great rapidity to high $s$, while the projecting needle end is shortened from a few millimeters beyond the post $P'$ to zero. When the needle point retreats just within the post, the curve drops instantly to zero.

To accentuate this result the thimble was cut down (the form is practically immaterial), admitting of larger $x$ between the same posts. The graphs, of which Fig. 5 gives an example, fully bear out the surmise, and the cusp has risen to nearly four times the height of the crests in figs. 1, 2, 3. What the larger $x$ insures is probably greater axial momentum of the ionized wind, and a point immediately in front of a surface of high potential gives the latter a longer range of action. Eventually the life of the ions is in question. Again the forms of the curves must depend essentially on the position of charged bodies, like the poles of the electric machine, near the field, as these deflect the air current. No pressures are observed until the charge of the machine exceeds a certain specific ionizing potential, after which the appropriate pressure ($s$) appears at once. In the reversed case pressure vanishes before the machine is discharged. My greatest difficulties thus far have



been the fluctuating potentials of the machine, due, so far as I can see, to the casual partial self-discharge within. Sputtering is fatal.

3. *Mucronate electrode.* Borrowing a term from the botanists, what is needed therefore is a slightly convex electrode $E'$ with a sharp fixed needle point projecting less than a millimeter from its center (see insert Fig. 6) and facing (convexities toward each other) a similar but unarmed electrode $E$. $P$, $P'$ are as before, 4.5 cm apart.

The results obtained with this mucronate electrode (Fig. 6) are astonishing; for the curve sweeps aloft in some cases to over five times the heights of the original crests. Thus far these graphs have not started until $x = .5$ cm is passed. They are peaked at the upper end, and drop from the sharp crest. They imply a degree of sensitivity that makes interferometer observation difficult, every little irregularity of the Wimshurst being magnified.

By placing the posts $P$ $P'$ 10 cm apart with a clear field between, the crest has been increased to $s = 250$. A good example of these results is given in a reduced scale in Fig. 7, which consists of two approximately linear branches on each side of the crest.

Micrometer results on the pressures $s$ as related to the inverse saliency of the needle point can not be given here; but I may mention that for a spark gap $x$ = 2 cm (30 *kv/cm*) a needle point projecting .005 cm beyond the effective limit of the electrode, gave a pressure $s = 560$, that is, 70 per cent. above the crest of Fig. 7, and about fifteen times the original sensitivity. Finally, it seems clear that the crests in Figs. 6 and 7 are to be associated with the limiting potentials of the machine, their $x$ position being an indication of the maximum field between electrodes.

Carl Barus

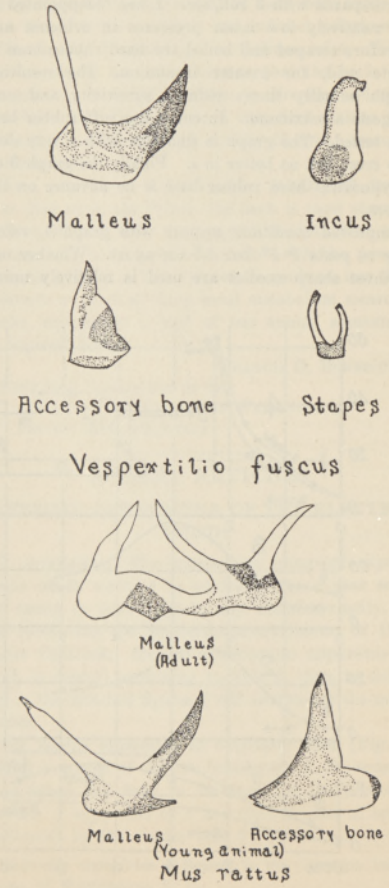
Brown University

## SOME PECULIAR AUDITORY OSSICLES

Three auditory ossicles are generally said to be present in animals which possess these bones. While making a study of the ossicles of several genera of bats, the author found four present in many instances.

Doran, in his famous monograph on mammalian auditory ossicles, has described and figured the ossicles from several genera of bats. The chief difference between the ossicles from the genera used in this study and those of Doran's is in regard to the head of the malleus. Each malleus which Doran studied possessed a well-developed head. In no case did a head exist on a malleus in this study. However, a fourth bone was usually found. This was located between the malleus and incus. It was entirely separated from the malleus, but in some cases it was found fused to the incus. This bone has probably become the head of the malleus in those animals which possess only three ossicles. It is designated in this study as the accessory bone. The fact that four ossicles are present in some bats suggested the idea that four ossicles may exist in other animals in earlier developmental stages.

Three ossicles are present in the adult white rat (*Mus rattus*). The malleus has a peculiar shape. The ossicles from an animal one day old were removed and studied. Four bones were found to be present. Two of these represented the malleus of the adult animal. The discontinuous lines in the figure of the adult malleus show the approximate place where the two bones fuse in the adult. Since four bones are found to exist in the young of this particular species, it is probable that they exist in






earlier developmental stages in other animals. Further study will be made on this point.

Clay B. Freudenberger

Colorado College

## THE NATIONAL ACADEMY OF SCIENCES

At the annual meeting of the National Academy of Sciences, held in Washington on April 25, 26 and 27, the following papers were presented:

*The nature of the insensible perspiration:* Francis G. Benedict and Cornelia Golay Benedict, Nutrition Laboratory of the Carnegie Institution of Washington. We have made numerous experiments, chiefly with one subject, in which the insensible perspiration has been analyzed, and the effects of environmental temperature, of the removal of clothing, and of a blast of air from an electric fan have been readily determined. Thus, a typical experiment showed in the preliminary period a total insensible loss, both from the lungs and skin, of 21.76 grams per hour, when the subject was nude in an environmental temperature of 25° C. In the next period, when the nature of the loss was studied, it was found that 7.58 grams per hour were lost from the skin, 8.13 grams were lost as water from the lungs, 17.08 grams of carbon dioxide were eliminated, and 15.36 grams of oxygen were absorbed. In another experiment at a room temperature of 20° C. the total loss, when the fan was blowing over the nude body, was 19.55 grams per hour. In a period immediately following, with the fan still going, 8.45 grams were lost from the skin, 7.29 grams were lost as water from the lungs, 22.54 grams of carbon dioxide were eliminated, and 19.81 grams of oxygen were absorbed. Although the results are in large part for one special subject, with whom experiments without clothing could be made, at least a dozen other persons have been studied with ordinary clothing, and the general deduction can be made that the total insensible loss in weight of the average woman, resting quietly, will be about 20 or 30 grams per hour. That of the average man will be nearer 40 grams per hour. Of this about 45 per cent. is in water from the skin, about 45 per cent. is in water from the lungs, and 10 per cent. represents the difference between the intake of oxygen and the output of carbon dioxide. The effects of the removal of clothing, of wind movement, and of temperature below the point when visible perspiration occurs are astonishingly small, chiefly because the skin temperature is profoundly lowered by such measures. The total insensible loss is a reliable index of the total metabolism and is finding use in modern clinics.

*The embryology of Equisetum debile Roxb.:* Douglas Houghton Campbell, Stanford University. The genus Equisetum includes about 25 species, the sole survivors of a very ancient group of plants. A knowledge of the embryo is therefore of great importance in determining their relationships to the other Pteridophytes. No comprehensive study of the embryo has been made since that of Sadebeck in 1878, although several contributions to the subject have been made since. A large number of gametophytes of *E. debile* was sent the writer from India. These contained great numbers of embryos in all stages of development, so that it was possible to secure an almost complete series showing the early history of the sporophyte. *E. debile* differs considerably in some of the details of the embryo from the species (*E. arvense, E. palustre*) studied by Sadebeck, and more nearly approaches *E. hiemale* and *E. variegatum*. The most important point brought out in these investigations is the origin of the buds from which the secondary shoots develop. These buds are of endogenous origin, and sometimes, at least, arise from the root, thus closely resembling a primitive form, Ophioglossum. This fact supports the view already expressed by the writer that there is a real, if somewhat remote, relationship between the Equisetineae and the most primitive ferns. Both from its size, and from the many sporophytes produced from it, the gametophyte of *Equisetum debile* is strongly reminiscent of certain liverworts, especially Anthoceros.

*Some aspects of protoplasmic surfaces:* W. J. V. Osterhout.

*The effect of tubercle bacilli and the chemical fractions obtained from analysis on the cells of the connective tissues in rabbits:* Florence R. Sabin and Charles A. Doan.

*The effect of small amounts of chemicals in increasing the life activities of plants:* F. E. Denny, Boyce Thompson Institute. Plants in a dormant or relatively inactive period may be stimulated into increased activity by chemical treatment. Thus, the processes of coloration, which take place in lemons and oranges during storage after removal from the tree, may be hastened by treatment with low concentrations of ethylene ($C_2H_4$). The time required for coloration is reduced to about one fourth the normal time by adding to the air surrounding the fruit 1 part ethylene to 10,000 parts of air. The life activities of the fruit as judged by the rate of respiration is doubled or even trebled by this treatment. Potato tubers when freshly harvested are dormant, and will not sprout if planted at once under favorable growing conditions, the rest period lasting from 1 to 4 months in different varieties of potatoes. This period of inactivity may be shortened by treating the tubers with various chemicals such as thiocyanates (SCN), thiourea ($N_2H_4CS$), and ethylene chlorhydrin ($C_2H_4ClOH$). The gain in time of sprouting is about 2 to 6 weeks, depending on the variety of potato and the stage of dormancy at the time the treatment is applied. Twigs of apple, grapes, lilac, etc., also have this dormant period in autumn, and the buds of these species can be forced into early growth by treatment with certain of these chemicals, the gain in time of budding or blooming ranging from 1 to 9 weeks. It is shown that these facts are related to the general problem of growth in plants, and in particular to the theory of the mechanism of growth control, and to the causes of correlations in the growth of plant buds. These results have

found application in practical agriculture in the case of certain plants, and the possibility of extending them to include other plants is discussed.

*The measurement of the heat production of nerve:* A. V. Hill, University of London. The nature of the impulse transmitted by nerve has been a subject of continual discussion and investigation by physiologists. The most obvious hypothesis that the wave transmitted by nerve is of a physical character, analogous to that of other physical waves, was supported by the fact that it had always been found impossible, even with the most refined methods, to detect any heat liberation in a nerve as the result of stimulation. Against this view, however, were other well-established experimental facts, particularly: (1) that without oxygen the nerve gradually loses its power of conducting; (2) that after the strength of an impulse has been reduced by passing through a narcotized region it rises again to its full value in a region of normal nerve beyond, and (3) that the velocity of transmission of the wave is largely affected by a change in temperature. Recent improvements in experimental methods have made it possible at last to measure the heat produced by nerve during stimulation, thus disposing finally of the purely physical hypothesis of the nervous impulse, especially since it has been found that, as in muscle, the heat can be divided up into several phases of which the most important is that of "recovery" following activity. The observations on the heat are in agreement with those of other observers (T. Lunberg, Parker, Fenn) who have reported an increase in the oxygen-consumption, or the $CO_2$-output of nerve, following stimulation. The chief instruments adopted were: (1) a thermopile containing three hundred constantan-silver couples in a space of 1.5 centimeters, with various devices to shield it from disturbances and errors, and holding about six nerves of small English or Dutch frogs, and (2) a pair of moving coil galvanometers, coupled by a thermal-relay, allowing readings to about $2 \times 10^{-12}$ amp., with a deflection time of about four seconds. With these it was found (employing 10 seconds of stimulation) that a *single* nerve impulse causes an initial rise of temperature of about $10^{-7}$° C., which is followed by a prolonged recovery phase in which about nine times as much heat is given out as in the initial phase. The heat per impulse is not constant but diminishes considerably as the frequency of stimulation is increased. This shows that after a wave of activity has passed along, the energy available for immediate use in a subsequent impulse has to be restored, and confirms the idea, based on other work, that a wave travelling in the immediate "wake" of another is of a diminished intensity.

*Physical, chemical and biological effects of high frequency sound-waves:* R. W. Wood.

*Additional evidence as to the intercellular formation of connective tissue:* George A. Baitsell (introduced by Ross G. Harrison).

*Generalizations of Waring's problem on powers:* L. E. Dickson.

*Relationships in the spectra of the elements of the first row of the periodic table:* R. A. Millikan and I. S. Bowen, California Institute of Technology. Practically all of the strong ultraviolet lines that can be emitted by the atoms of the first row of the periodic table in all stages of ionization of the valence electrons have now been obtained and a general statement of the relationships between the frequencies of these lines has been formulated. These relationships are presented most simply and compactly in a new graph which depicts the generalized form of the Moseley law in the field of optics. Similarly, a table of the ionization potentials of the atoms of the first row in all stages of ionization. Furthermore, the predictions of the Russell-Heisenberg-Pauli-Hund theory as to the structure of spectra in general have been completely verified in the case of these light elements.

*Polarization of light by reflection from rough rock surfaces, with special reference to the materials exposed at the moon's surface:* F. E. Wright, Geophysical Laboratory of the Carnegie Institution of Washington. In the study of the surface features of the moon it is desirable to ascertain, if possible, what kinds of materials are exposed there. Our best approach to this problem is through the aid of the sun's rays that serve as messengers from the moon to us. We view the moon by reflected sunlight and we know from measurements that the reflected sun's rays differ slightly from the direct sun's rays. These differences are produced on reflection at the moon's surface; from these effects, in turn, we can draw certain conclusions regarding the reflecting substances themselves. For this purpose we measure the amount of polarization in the light reflected by the moon at its different phases, and also ascertain to what extent rough surfaces of rocks and other materials polarize light on reflection. An extended series of measurements on different kinds of rocks, such as basalt, diabase, gabbro, dunite, serpentine, diorite, granite, obsidian, pumice, quartzite, shale, sandstone, limestone, marble, etc., has been made. The results show that only highly siliceous rocks, such as pumice, siliceous sinter, granite, quartzporphyry, also sulfur, and powders of transparent substances, but not basalts and other basic rocks low in silica, produce polarization effects similar to those observed in the rays reflected by the moon. The amount of polarized light in the rays reflected by the moon is slight at all angles of incidence and is practically nil at new and at full moon.

*High dispersion stellar spectra and some results of a study of Cygni:* Walter S. Adams and Alfred H. Joy, Mount Wilson Observatory. The use of the 100-inch telescope at Mount Wilson and a large stationary spectrograph has made it possible to photograph the spectra of stars on a scale larger than any employed regularly hitherto. These spectra are especially well adapted for the study of the identification and behavior of different classes of lines, accurate determinations of radial velocity and the displacements of lines of different elements. A special study of the spectrum of Cygni, a star of spectral type very similar to that of the important Cepheid variables, has resulted in the identification of many lines



previously unknown. Most of these belong to the spectrum of the ionized elements. The spectra of the rare earths, especially cerium, neodymium and samarium, are prominent and the entire spectrum is very similar to a reversed solar flash spectrum as seen at a total eclipse. Measurements of the ionized cerium lines indicate that the low-level gases of this element of high atomic weight are rising in the stellar atmosphere at a velocity of about 1.4 km./sec. as referred to the normal iron vapor. The presence of convection currents in the atmosphere of the star is also confirmed by the displacements toward longer wave-lengths of the lines due to ionized elements with reference to the lines of the normal atom.

*The relationship of spectral type to period among variable stars:* Walter A. Adams and Alfred H. Joy, Mount Wilson Observatory. A knowledge of the relationship between length of period and spectral type among variable stars, especially those of the Cepheid type, is most desirable in view of their importance in the study of stellar distances. While it has been known in a general way that the spectral type is more advanced the longer the period, no accurate correlation has been established because of the difficulty of the accurate spectral classification of these faint stars. A study of over 60 of these variables with the 100-inch telescope at Mount Wilson provides the material for such an investigation. It is found that a large majority of the Cepheids, including all of the brightest and best known stars, show very nearly a linear relationship between spectral type and the logarithm of the period. The few exceptions all have spectral types which are less advanced than would be expected from their periods, and may perhaps form a separate group allied to the irregular variables. The comparison of the results for the Cepheids with those for the short-period cluster-type stars and the long-period red variables gives the rather surprising results that these two classes fall on the average close to the curve derived from the Cepheids. The cluster-type variables, however, show considerable range in spectral type with but little range in period, although their mean values are in good agreement with those of the Cepheids. The conclusion seems to be justified that the physical cause of the variation in light of these different classes of variable stars is similar and probably is to be ascribed to a periodic variation in size.

*The variation of the absorption of X-rays with wave-length:* F. K. Richtmyer, Cornell University. The systematic way in which the absorption of X-rays by various media varies with the wave-length of the rays and with the atomic number of the absorber has stimulated attempts, both theoretical and experimental, to determine the exact law involved. Several formulae have been proposed on theoretical grounds, which predict that, after eliminating scattering, the absorption varies as the cube of the wave-length ($\lambda$). This proposed law is approximately verified experimentally. But, as pointed out by the author (*Phys. Rev.*, July, 1921), and as has been found by other investigators, there are slight deviations from the cubelaw over wide spectral ranges. Recently Oppenheimer (*Zeit. für Physik.*, Feb. 14, 1927), on the basis of the new Schrodinger theory, deduces that the exponent of $\lambda$ should be $3+\beta$, where $\beta$ is a small fraction which varies from $+0.3$ to $-0.3$. It seemed desirable to obtain data, as precise as might be possible, to check Oppenheimer's conclusions. By methods previously described, and by use of a high-power water-cooled X-ray tube, the author has investigated the absorption coefficient of Sn, on the short wave-length side of the K absorption limit, using a spectrometer with very narrow slits. Within the limits of experimental error (not greater than 0.2 per cent.) a curve plotted between the absorption coefficient and the cube of the wave-length is rigorously a straight line from the absorption limit ($\lambda = 0.42$A) down to about 0.27A: *i.e.*, in this range $\beta$ is zero. Below this wave-length observed values of the absorption coefficient are consistently lower than would be predicted by the straight line: *i.e.*, $\beta$ may have a small positive value in this region. The exact determination of $\beta$ presents serious experimental difficulties, partly because of the unknown correction for scattering, partly because of the limitations of precision inherent in measurements of this kind. The author takes pleasure in acknowledging assistance from Mr. L. S. Taylor in making the observations. The investigation was supported in part by a grant from the Heckscher Research Council of Cornell University.

*Theory of normal cathode fall:* K. T. Compton and P. M. Morse, Princeton University. The problem has been attacked from the standpoint that the field in the cathode fall space is so distributed as to give maximum ionization, subject to the restrictions imposed by Poisson's equation. This principle, together with the experimental values of the cathode fall $V_n$ and of the average number of ionizing collisions $\alpha$ made by an electron in unit path, enables us to calculate the thickness of the cathode dark space $d_n$ and the current density $j_n$ for any gas at any pressure and with any cathode material. These calculated values are in rather good agreement with experimental observations. The factors which determine $V_n$ are discussed, but independent evidence on this point is not available. $V_n$ is the least potential drop which (given its most favorable distribution) can produce enough ionization to insure a continued supply of electrons from the cathode under positive ion bombardment. The number of positive ions required to liberate one electron under these most favorable conditions is found to vary from 21.5 to 109 for different gases and a Pt cathode. The most favorable potential distribution gives results which are quite consistent with Poisson's equation. Provided the current j does not exceed $A j_n$, where A is the cathode area, it is shown that the cathode drop must remain constantly $V_n$ independent of the current. If $j > A j_n$, however, it is shown that the most favorable potential distribution is no longer consistent with Poisson's equation. If in this case we take, as the true potential distribution, that one which is most favorable *subject to the limits imposed by Poisson's equation*, we get approximately the relations which are known to be true of the *abnormal*

cathode fall. This case has not yet been quantitatively worked out, however. In general the present theory appears to be much more satisfactory than any previous theory of the cathode fall as regards the number of phenomena explained, the quantitative agreement of theory with observation, and the general reasonableness of the mechanism of the discharge.

*Special distribution of the photo-electrons ejected by X-rays:* E. C. Watson, California Institute of Technology. The experiments of Wilson, Auger, Bothe, Bubb, Loughridge, and Kirchner by the C. T. R. Wilson expansion chamber method have shown that the most probable direction of the photo-electron tracks in a gas traversed by X-rays is nearly the direction of the electric vector of the incident wave, but with an appreciable forward component. There is, however, a very considerable variation in the direction of the tracks. Magnetic spectra of the electrons ejected from very thin metallic films at various angles show similar effects. Theories making use of orbital velocities inside the atom to account for this apparent emission from the atom over a wide range of angles instead of in one definite direction have been proposed by Bothe, Bubb and Auger and Perrin. It can be shown, however, that simple nuclear scattering must be present in all the experiments in sufficient amount to account for the distribution in direction, and the Rutherford theory of nuclear scattering leads to a distribution function which fits the facts much better than any of the more elaborate theories. The simplest conclusion then is that all the electrons ejected from an atom by X-rays start out in the same direction. This leads to a great simplification in our conception of the nature of the force exerted on an electron by a field of radiation.

*Preliminary revision of Rowland's tables of solar spectrum wave lengths:* Charles E. St. John.

*Application of the law of similitude to hydraulic laboratory research:* George deThierry, Technische Hochschule, Berlin-Charlottenburg, Germany. Application to hydraulic laboratories is based on Newton's theorem 26, Section 7, like bodies in like situations are considered to be moved among themselves with like motions and in proportional times. Relations resulting from geometrical analogy are given for linear superficials, volumes, velocities, time intervals, water discharge, forces, energy, momentums, friction head. Difficulties in application of laboratory investigation to river problems. Dr. Krey's formula for evaluating quantity of débris.

*Report on the ether-drift experiments at Cleveland in 1927:* Dayton C. Miller, Case School of Applied Science. The ether-drift interferometer which was used at Mount Wilson in California in the experiments of 1921–1926 has been mounted on the campus at Case School of Applied Science in Cleveland. Only minor changes, suggested by experience, have been made in the apparatus. Special precautions have been taken to obviate troubles caused by vibration from city traffic. A series of observations which will extend throughout the year, comparable with those made at Mount Wilson, is now in progress. The results for the first epoch of the series indicates an effect of the same order of magnitude as was obtained at Mount Wilson and consistent with the conclusions previously announced.

*Periodicity in solar radiation:* C. G. Abbot, Smithsonian Institution. The author submitted monthly mean values of the solar constant of radiation for the years 1918 to 1926, in which certain systematic errors discovered by statistical methods have been eliminated. In these values a variation associated with the sun-spot cycle of 11 years is plainly visible. Higher solar radiation values attend increased sun-spot activity. A periodicity of 25 2/3 months having been noted, the values for 77 consecutive months, ending October, 1926, were submitted to Professor Dayton C. Miller for treatment by means of his harmonic analyzing machine. The result was exhibited graphically. The sun-spot period of 11 years could not be clearly shown by the machine (because it was operating on only 6½ years) and was represented imperfectly by the first and second components. The third component, 77/3 months, was very strong, and the fifth, 77/5 months, and seventh, 77/7 months, fairly strong. Also the overtones 77/6, 77/9, 77/12, 77/10, 77/14, were moderately conspicuous. These periodicities substantially make up the whole solar variation shown in the monthly mean values since May, 1920, except that due to the sun-spot cycle. It will be noted that the period 77/5 is substantially that found in world-precipitation by Professor Dinsmore Alter, and that the period 77/7 is that found by Clayton and Abbot several years ago. The resolution of hitherto apparently irregular solar variation into regular periodicities is interesting, and if confirmed by future observations may lead to forecasting methods of value.

*A redetermination of the Newtonian constant of gravitation:* Paul R. Heyl, United States Bureau of Standards. The present accepted value of the Newtonian constant of gravitation rests upon the independent work of Boys and Braun thirty years ago. As discussed by Poynting (Article "Gravitation," Encyclopedia Britannica) the accepted value of this constant has been taken as $6.66 \times 10^{-8}$, with an uncertainty of one unit in the third significant figure. About three years ago the Bureau of Standards undertook a redetermination of this constant with the object of obtaining another decimal place. The method was that of a torsion pendulum in a vacuum as used by Braun, observing the difference in the time of swing of the pendulum with the large attracting masses in the near and in the far positions. The two times of swing differed by five and one half minutes, the corresponding difference obtained by Braun being about forty-six seconds. The results so far obtained confirm the present accepted value and add the desired figure.

*Differential invariants of irregular elements:* Edward Kasner.

*(To be continued)*

# SCIENCE NEWS

*Science Service, Washington, D. C.*

## FOSSIL IMPLEMENTS IN PLIOCENE DEPOSITS

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HAS Nebraska produced the most ancient evidence of the existence of man yet known to science? This question is raised by Dr. Henry Fairfield Osborn, president of the American Museum of Natural History, in a report to the American Philosophical Society in which he describes investigations conducted by him in collaboration with Albert Thomson, of the American Museum staff. Fossil bone implements in geologic strata have been unearthed that may be some 4,000,000 years old, an age known to geologists as Pliocene.

Since past opinion has been that the most ancient evidences of man were to be found in the Old World, and since claims of the discovery of man in America antedating the Indians, some 25,000 years ago, have been received heretofore with skepticism, the announcement of Dr. Osborn, one of the world's leading authorities on the antiquity and evolution of man, will create great scientific interest.

Over 300 implements of forty different types have been discovered. They are made of the bones of extinct animals that lived in Pliocene times, but time has caused them to be turned into stone. These are the first completely fossilized bones to be discovered. Among the animals whose bones are represented in the collection are extinct horses, camels, deer, elephants and mastodons.

The exact locality in which the discovery was made has not yet been announced with further detail than to state that it is in western Nebraska. Dr. Osborn explained that he desired to protect the site from curiosity seekers who might interfere with the scientific investigations. The first of these artifacts were discovered about two years ago and since that time tractors and other modern machinery have been used in excavating the area. Two localities about 75 feet apart have produced most of the implements.

The fossilized implements are described by Dr. Osborn as of undoubted human origin and of symmetrical shape. Among them are skin dressers for cleaning animal hides, pointed awl-like implements evidently used in sewing, neck ornaments made of strung bones and a kind of comb that seems to be a tattooing implement. Eighteen of the types of tools have been matched with counterparts found in the ruins of cliff dwellers of the arid regions of the Southwest and one type can be nearly duplicated by a much more recent implement from the shell heaps of eastern America. Dr. Osborn stated that the fossilized bone implements he has found are just as real artifacts of human handiwork as are the famous worked flints of Europe. But unlike the implements of Europe which are usually weapons and hunting tools, the Nebraska artifacts are nearly wholly related to the peaceful arts. Further investigations are to be carried on this summer.

The discovery of evidences of ancient man in Nebraska, the native state of William Jennings Bryan, recalls that a fossil tooth found there several years ago by Harold Cook was ascribed by Dr. Osborn to a new type of ancient man, who may have been the maker of the tools and ornaments now unearthed. Dr. Osborn's discoveries also lend added interest to the recently reported discovery by investigators at the Colorado Museum of Natural History of evidences of ancient man in Pleistocene deposits in three widely separated localities in the West.

## CHEMICAL ANALYSIS OF THE TUBERCULOSIS GERM

CHEMICAL analysis of the germ that causes tuberculosis has led to the discovery of a new type of compound, a phosphorus-containing fat, which has peculiar biological properties, according to Professor R. J. Anderson, of the department of chemistry at Yale University.

The tuberculosis bacterium is unique among single-celled organisms in being the possessor of a waxy covering which renders it highly resistant. This is why it can defy the phagocytes which police the body, for instead of being dissolved by them and destroyed, the T. B. organism survives and may multiply after being engulfed. The waxy sheath is so thick that it makes up one fifth to two fifths of the weight of the dried bacteria.

Professor Anderson extracted eight pounds of the germs with a mixture of alcohol and ether to dissolve out this waxy coating. He obtained a pound of wax, half a pound of fat proper, and half a pound of phosphatide or phosphorus-containing, fat-like substance. The last material, to which he has given the name phosphosucride, is the most unusual constituent of the germs. It has been shown to contain phosphoric acid, a sugar and fatty acids. This compound differs from all other known phosphorized fats, according to Professor Anderson, and it may be expected to have peculiar biological properties.

While the biochemist is busy probing the formula of the phosphosucride, other investigators are studying it biologically at the Rockefeller Institute for Medical Research, to determine to what extent the destructive powers of the tubercle bacillus are due to this element in its make-up, and whether once identified, it will be of service in the treatment or prevention of the disease.

Other chemists in an analogous way have obtained specific chemical compounds from pneumonia bacteria, which show promise when applied clinically.

## THE EUROPEAN FISH TAPEWORM

THE dangerous fish tapeworm of Europe, the largest of the parasites that commonly attack human beings, has become established in the United States, and is to be the object of special study this summer by a group of investigators backed by the National Research Council and under the immediate direction of Professor H. B. Ward, of the University of Illinois, foremost authority on internal parasites. They will go to the extreme northern part of Minnesota, which is the center of the

threatened area in this country, and spend the summer tracing the connections of the infestation, which is complicated by the fact that the worms live part of their lives in fish and the rest in human beings and other warm-blooded creatures.

Fish tapeworms is a relatively common affliction among the peoples around the Baltic Sea, and is said to occur also to some extent in Switzerland. In some cases it does relatively little harm, while in others it induces an extreme condition of pernicious anemia, which sometimes ends in death.

Professor Ward states that the infestation was introduced by immigrant laborers in the iron and lumber industries, who not only carried the parasites internally but also imported their favorite dried and salt fish from the homelands. Salting does not kill the pest, and imperfect smoking also leaves it alive. There is evidence now, however, that the native fishes in some of the northern lakes may have become infested, and it is to ascertain the truth or falsity of these reports and to work out methods of keeping the infestation from spreading that the expedition under Professor Ward is to take the field this season.

## THE MISSISSIPPI FLOOD AND FLOOD PREDICTIONS

THE greatest flood in Mississippi River history, now raging, gave the first grim warning of its approach eight months ago.

"The present flood began late in August when heavy rains set in, raising the waters of one or two rivers in Kansas and Oklahoma," according to the following statement by H. C. Frankenfield, head of the division of rivers and floods of the U. S. Weather Bureau.

"In October there was flood in the Arkansas and Neosho rivers with damage of $40,000,000, or perhaps more. Last fall, I saw mud clots on ten-foot corn stalks, out in the prairie. Then, the rains drifted eastward, over Missouri, Illinois, Ohio, Tennessee, Kentucky and the Cumberland. And all this was at a time of the year when the rivers of the Mississippi system should have normally been at their lowest level.

"We know then that if the rains of the coming winter and spring were much above normal, we were going to have a big flood. But we can not forecast rains, and of course we could not predict the volume of the present torrent.

"Late in December rains swept Tennessee and Kentucky, and the next report was that all records were broken in the Cumberland River and there was a high flood in the Tennessee, and these are the two largest tributaries of the Ohio River. Heavy rain put the Ohio in flood in January, and then the rains became more widespread. During March, every tributary of the Mississippi, from the Des Moines southward and eastward, was in flood.

"There is no question that the present flood is the greatest that has ever covered the Mississippi. The flood of 1922 was the next greatest, and that of 1882 ranks third."

Flood warnings are sent out from the U. S. Weather Bureau every day in the year to some parts of the United States, sometimes four weeks in advance, sometimes only 18 hours. The Mississippi flood waters gather from such distant streams and have been studied so long and carefully that height and speed of the spring flood in the lower Mississippi can usually be estimated by bulletins several weeks before it sweeps through Louisiana.

"The prediction of floods is perhaps the most exact forecasting that we do," said Dr. Charles F. Marvin, chief of the U. S. Weather Bureau. "The prediction side is far ahead of the prevention measures that can be taken."

The bureau's flood warnings are instantly heeded by the people of the region involved, even though the country at large hears very little about a flood until the water reaches an alarming state. Engineers and levee boards organize their workers and get out their equipment. The dykes are strengthened, inhabitants are notified. But along the lower Mississippi many thousands of the people are Negro farmers and laborers and their families, people who often stick to their homes and trustingly climb up to the rooftops when the river menaces them, rather than escape when warned.

Many of these river dwellers, even if they have escaped with their lives, have now seen their homes wrecked. They have lost their best chance to plant their cotton or other crops, and unless the weather favors them, they may fail to get a crop in at all.

So long as men try to hold the Mississippi and its contributing streams within narrow bounds, so long men will have to keep close watch on the flood hazard, according to Dr. Marvin. In past ages, the river handled the problem in its own way, and made huge drainage areas. But men have built over 2,000 miles of levees to guide the river within a convenient channel. The levees are supposed to stand the strain of the torrent and they hold up remarkably, but if the water seeps in through a small leak in the wall, the rift may grow and the flood may force its way through, as it did at Dayton in the famous flood of 1913. Even though the walls of the levees are built higher and higher, and though they are pushed back from the river bank, even two miles in some places, the river may in emergencies demand and take more room.

Several hundred dollars spent in a laboratory study of floods would prevent millions of dollars loss, John R. Freeman, former president of the American Society of Civil Engineers and the American Society of Mechanical Engineers, said recently in commenting on the floods.

"The Federal Government and the states have spent hundreds of millions of dollars in trying to solve the Mississippi's problems, but it is still possible for one break in a levee to lay waste 5,000 square miles of as fertile land as the sun shines on, with a loss of $25,000,000 almost overnight," said Mr. Freeman, who accompanied President Roosevelt on his official inspection of the completed Panama Canal in the capacity of expert adviser. He was also consulting engineer for the Chinese Government, and has studied flood and river problems in that country.

"A week's work with a model, in which changes of shape and position can be readily made, at a total cost of

a few hundred dollars, may tell more than six months' effort and $10,000 spent on an experimental dike or groyne in the field. Coefficients of the relation between model and full size original can soon be established and after the variants have been determined on the model, one can go ahead with great confidence in the field.

"The experiments by Froude on towing ship models in a long laboratory tank were at the very foundation of progress in the design of naval and merchant vessels, and it is entirely within reason that similar improvements in the art of training rivers to maintain navigable channels without frequent expensive dredging and in making them carry their floods to the sea more safely and quickly, may come from the laboratory."

## INDIAN MOUNDS AS FLOOD REFUGES

THE thousands of terror-stricken people who have taken to Indian mounds to escape the flooding Mississippi waters are showing scientists how the Indians probably used these earthworks which they built in pre-Columbian days.

Each of these mounds, very frequent in this section, can take care of some 500 persons. Sturdily built of earth, they have resisted the onslaught of the waters for generations, and are now pinnacles of safety to the refugees.

The situation to-day, according to Dr. Alfred Kidder, the well-known American anthropologist, is strong evidence in favor of the theory that the mounds were originally built by the Indians a thousand years ago for this very purpose—to afford refuge from floods. Undoubtedly the Indians experienced floods of considerable magnitude and had to find some method of protecting themselves.

"In all probability," said Dr. Kidder, "it was for this purpose that they toiled for years to build these high mounds. It was a gigantic task since they had only their baskets in which to carry the tons of earth necessary to make them.

"It was at first thought that these mounds might be funeral piles like other smaller mounds in this section and in the Ohio valley, but excavations unearthed no human remains. However, post holes were discovered where the framework of buildings had evidently been erected. Baked clay was also discovered. This clay had plastered the log and twig structure of the building and was hardened into enduring form when the buildings caught fire.

"Were these mounds erected merely as high places for temples as in the case of the Aztec and Toltec pyramidal structures? was the conjecture. Against this theory arose the remote possibility that the mounds were places of refuge from floods—a theory substantiated by the present situation.

"The buildings were probably temples, altars and the habitats of chieftains," said Dr. Kidder. "In time of flood a mound could accommodate the entire tribe, most of the members of which probably lived in the inundated area."

Pyramidal in structure, but with a flat top to permit erection of buildings, the mounds are about 150 feet in diameter and some fifty feet high. They are largely confined to the flood area of the Mississippi. A number occur, however, in areas in the valley which are not completely inundated in flood time. These were probably built later, Dr. Kidder said, in the manner of primitive peoples, after the erection of such mounds had become a custom. The funeral mounds, on the other hand, are much smaller and lower and occur frequently in both the Mississippi and Ohio valleys.

## ITEMS

A SCALY monster of the pre-human ages of the earth, surviving into modern times in the almost unvisited swampy fastnesses of southern Java, is reported to the scientific journal, *Die Umschau*, by Dr. P. Vageler. It is described as a one-horned rhinoceros, related to a form already known elsewhere in the East Indies, but differing from it in that its almost naked hide is closely covered with small, hard, horny scales. It also has enormous front teeth, like those of a hippopotamus. It has often been described by the natives, but Europeans were incredulous, regarding these reports as folklore. A few professional hunters among the whites had killed specimens; but they could obtain such high prices from the Chinese, who use the hide and horns of rhinoceroses in medicine, that they were secretive about the business and did not share their knowledge with scientists. Finally, however, photographs were brought out of the jungle, showing very clearly that the animal is new to science. Now that its existence has been authenticated it is expected that efforts will be made to secure living specimens for zoological gardens.

G. K. NOBLE and M. E. Jaeckle, of the American Museum of Natural History, confronted with the troublesome fact that frogs and toads and spotted salamanders and all manner of other interesting but non-fur-bearing creatures can not be successfully stuffed and mounted by the ordinary methods of taxidermists, have solved the problem by pickling them in solid paraffin wax. They first remove all trace of water from the specimens by appropriate chemical means, arrange the little animals in natural positions, and soak them for several days or weeks in melted paraffin, until every tissue is thoroughly impregnated. By this method reptiles and amphibians can be worked into naturalistic museum groups and made as "alive" looking as birds and fur-bearing animals, instead of being pallid corpses pickled in jars of alcohol. They keep their natural colors indefinitely, except that sometimes their eyes need to be touched up with a little gold paint.

A GERMAN artist-inventor has devised a new technique for turning plaster statues into metal ones, by means of an ingenious "extrusion pistol" which projects a fine stream of melted bronze or other metal against the inside of a hollow plaster cast with such force that it carries on through the porous substance and comes out as a thin film, hardening on the outer surface. The process is said to be rapid, five minutes' operation of the pistol being sufficient to metallize a plaster cast the size of a man's hand.

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# Kausalität und Statistik in der modernen Physik[1]).

Von P. JORDAN, Göttingen.
(Aus dem Institut für theoretische Physik der Universität.)

Sehr verehrte Anwesende!

Die Entwicklung der Physik in den letzten Jahrzehnten hat immer wieder grundsätzliche, erkenntnistheoretische Fragen in den Vordergrund gebracht. In der Relativitätstheorie ist das Raumzeitproblem vorläufig abschließend geklärt worden. Neue Fragen sind mit der Quantentheorie aufgetaucht. Zu ihnen gehört besonders eine Frage: Gibt es eine Kausalität im elementaren physikalischen Geschehen? Ist das Schicksal der Atome vollständig determiniert, oder gibt es Lücken in der kausalen Bestimmtheit der elementaren Ereignisse?

Die Physiker zweifeln heute nicht mehr daran, daß die Frage nach dem Vorhandensein einer vollständigen Kausalität nur durch die Erfahrung entschieden werden kann — daß also die Kausalität nicht etwa eine aprioristische Denknotwendigkeit ist. Zwar ist ein gewisses Maß von Kausalität notwendige Vorbedingung für die Möglichkeit einer physikalischen Wissenschaft sowohl als auch überhaupt eines menschlich geregelten Daseins. Und glücklicherweise besteht ja in unseren makroskopischen Dimensionen eine anscheinend ausnahmslos zuverlässige Kausalität. Aber für das atomare Größengebiet folgt daraus zunächst nicht mehr, als daß es im statistischen Mittel kausalen Gesetzen unterliegt. Es bleibt die Frage, ob auch dem einzelnen Atom sein Schicksal vollständig vorgeschrieben ist.

Vor ihrer Erörterung wird es nützlich sein, zunächst einmal dem Begriff der Kausalität eine genauere Betrachtung zu widmen. Der Physiker kann sich nicht zufrieden geben mit der ungefähren Vorstellung, die wir vom Sinn dieses Wortes besitzen. Er hat auch kein Interesse für die metaphysischen Bedeutungen, die ihm von manchen Philosophen beigelegt werden. Die Kausalität definieren heißt für den Physiker nichts anderes, als angeben, wie man ihr Vorhandensein oder Nichtvorhandensein experimentell feststellen kann. Damit ist bereits klar, daß auch die Definition der Kausalität sich fortschreitend verändern muß mit dem Fortschritt unserer Anschauungen, Kenntnisse und experimentellen Mittel. Betrachten wir also zunächst die Rolle der Kausalität in der klassischen Feldphysik!

Die klassische Feldphysik behauptet, daß man die physikalische Wirklichkeit beschreiben kann — wobei wir das Wort „beschreiben" hier gewissermaßen im rein geographischen Sinne gebrauchen wollen — indem in einem vierdimensionalen Raum-Zeitgebiet für jeden Punkt gewisse meßbare Größen — Feldstärken, Gravitationspotentiale usw. — zahlenmäßig angegeben werden. Und dabei besteht eine Kausalität in folgendem Sinne: Denken wir uns ein endliches Stück des Raumes abgegrenzt; etwa in Form eines Kastens. Wir wollen nicht näher darauf eingehen, wie unsere Formulierung unter exakter Berücksichtigung der relativistischen Raum-Zeitverhältnisse durchzuführen wäre — was natürlich keinerlei Schwierigkeit machen würde. Zu einer bestimmten Zeit — sagen wir um 11 Uhr — möge der physikalische Zustand innerhalb des ganzen Kastens vollständig bekannt, vollständig ausgemessen sein. Ferner soll der physikalische Zustand auf der ganzen Oberfläche des Kastens von 11 Uhr bis 12 Uhr dauernd kontrolliert werden. Durch die so festgestellten Umstände sind die physikalischen Vorgänge im Innern des ganzen Kastens von 11 bis 12 Uhr eindeutig bestimmt: Reproduziert man zu beliebiger Zeit an beliebigem Orte den Anfangszustand des Kastens und den zeitlichen Verlauf der Vorgänge an seiner Oberfläche, so reproduzieren sich von selbst alle Vorgänge im Innern des Kastens. Innerhalb eines gewissen Zeitintervalls — von der Größenordnung Kastendurchmesser dividiert durch Lichtgeschwindigkeit — sind die Vorgänge in der Mitte des Kastens sogar unabhängig von denen an der Oberfläche.

Dies sind Behauptungen, die einer experimentellen Prüfung fähig sind. Freilich muß dabei ausdrücklich vorausgesetzt werden, daß der Anfangszustand im Kasten nicht etwa derart verwickelt ist, daß seine vollständige physikalische Ausmessung völlig unmöglich wird. Man wird also beispielsweise den Fall ausschließen müssen, daß ein lebendes Tier in dem Kasten sitzt — die Vorstellung, daß man auch dabei eine genaue Ausmessung des physikalischen Zustandes durchführen könnte, entfernt sich allzuweit von allem praktisch Möglichen. Für die Zwecke der Biologie muß das Kausalitätsprinzip und das Kausalitätsproblem wesentlich anders und komplizierter formuliert werden als für die Physik.

Aber bleiben wir bei der physikalischen Kausalität! Es muß betont werden, daß diese Kausalität etwas sehr Merkwürdiges ist. Sie ist durchaus nicht gleichbedeutend mit der Existenz physikalischer Gesetze überhaupt — mit der Existenz mathematischer Beziehungen zwischen den physikalischen Größen im Weltgebiet. Es herrscht zudem eine eigenartige Unsymmetrie zwischen den räumlichen und der zeitlichen Weltkoordinate: Nämlich es besteht gemäß dem Kausalitätsprinzip zwischen gewissen zeitlich getrennten Weltgebieten

[1]) Habilitationsvortrag.

eine physikalische Abhängigkeit; zwischen räumlich getrennten Gebieten besteht eine solche Abhängigkeit nie.

Theoretisch begründet ist das Kausalitätsprinzip der Feldphysik in zwei Umständen, die wir hier nur ganz kurz bezeichnen wollen, ohne auf den mathematischen Beweis dafür einzugehen, daß sie wirklich die Gültigkeit des Kausalitätsprinzips in der erläuterten Form gewährleisten: Erstens sind die physikalischen Gesetzmäßigkeiten, d. h. die mathematischen Beziehungen, denen die Feldgrößen genügen, nichts anderes als Differentialgleichungen, und zwar in erster Annäherung hauptsächlich lineare partielle Differentialgleichungen zweiter Ordnung. Zweitens muß man bekanntlich, wenn man eine möglichst einfache Geometrie im vierdimensionalen Weltgebiet haben will, bei welcher der Phythagoreische Lehrsatz gilt, nicht die Zeit selbst, sondern die imaginäre Zeit als Weltkoordinate einführen. Dieser Umstand ist sehr wesentlich. Wenn statt dessen die vierdimensionale Welt vier reelle Dimensionen hätte (während gleichzeitig die allgemeinen physikalischen Gesetze, also die Differentialgleichungen des Elektromagnetismus und der Gravitation unverändert blieben), so würde es gewissermaßen viel mehr als Kausalität geben: Man würde aus der genauen Kenntnis eines kleinen Weltgebietes den physikalischen Zustand zeitlich oder räumlich beliebig weit entfernter Weltgegenden ableiten können. Wenn dagegen die Welt nur zwei reelle und außerdem zwei imaginäre Dimensionen hätte, so würde es keine Kausalität mehr geben. Es könnte dann vorkommen, daß innerhalb eines abgeschlossenen Kastens plötzlich Bewegungen auftreten würden, ohne daß dafür eine Ursache im Innern des Kastens vorhanden gewesen oder durch die Wände hereingekommen wäre. Dies ist also die Bedeutung des Kausalitätsprinzips in der Feldphysik: Es ist nicht etwa selbst ein Naturgesetz — Naturgesetze sind die Differentialgleichungen, denen dies physikalische Feld unterliegt. Sondern es ist eine mathematische Folgerung aus den Naturgesetzen, ein auf die Naturgesetze angewandter Lehrsatz aus der mathematischen Theorie der hyperbolischen Differentialgleichungen.

Man muß also wirklich darauf gefaßt sein, daß das Kausalitätsprinzip verlorengehen könnte, wenn man von der klassischen Feldphysik übergeht zur Quantentheorie. Denn hierbei erfahren ja gerade diejenigen physikalischen Grundannahmen eine einschneidende Veränderung, welche wir als theoretische Ursachen für die Gültigkeit des Kausalitätsprinzipes bezeichnet haben. Schon die Beschreibung der physikalischen Wirklichkeit kann, wie wir jetzt wissen, nicht in der von der klassischen Physik angenommenen Weise durchgeführt werden: Die physikalischen Größen sind nicht stetig im Weltgebiet ausgebreitet; die physikalischen Bewegungen erfolgen nicht in durchweg stetiger Weise; sondern es gibt elementare Unstetigkeiten, es geschehen Quantensprünge. Was dabei von der Kausalität ersichtlich übrigbleibt, ist zunächst nichts weiter als eine statistische Kausalität. Wenn wir mit sehr vielen gleichartigen Atomen experimentieren, oder wenn wir ein mit wenigen Atomen durchzuführendes Experiment zahllose Male wiederholen, dann kommen wir immer zu einem Ergebnis, das mit dem Kausalitätsprinzip in Einklang ist. Wir haben uns vorhin überlegt, daß physikalische Gesetzmäßigkeit und physikalische Kausalität durchaus nicht dasselbe sind. Es ist deshalb nicht überflüssig, zu betonen, daß es sich bezüglich der physikalischen Gesetzmäßigkeit in diesem Punkte genau so verhält, wie bezüglich der Kausalität: Alles, was wir bis heute kennen, ist im wesentlichen statistische Gesetzlichkeit.

In der Erkenntnis dieser Gesetzlichkeit sind bekanntlich in letzter Zeit wichtige Fortschritte erzielt worden. Man kann heute z. B. das mit den Bewegungen der Elektronen im Innern eines Atoms verknüpfte Spektrum im Prinzip ebenso zuverlässig berechnen wie nach der klassischen Mechanik die Bewegungen der Planeten. Aber obwohl der Gang der Rechnung in beiden Fällen ein sehr ähnlicher ist, besteht doch ein wesentlicher Unterschied in der Bedeutung der Rechenergebnisse: Die klassische Rechnung gibt uns Aufschluß über das Schicksal gerade unseres speziellen Planetensystems. Die quantenmechanische Rechnung liefert im allgemeinen keine Aussagen über ein bestimmtes einzelnes Atom, sondern nur Mittelwerte über eine große Menge gleichartiger Atome. Man kann zwar aus der quantenmechanischen Rechnung beispielsweise die Energie eines einzelnen Atoms in einem gewissen Zustand exakt entnehmen — aber nur deshalb, weil diese Energie gerade für alle Atome dieses Zustandes dieselbe ist — so daß die Energie des Einzelatoms identisch ist mit ihrem Mittelwert über viele Atome. Betrachten wir jedoch z. B. das Verhalten des Atoms unter dem Einfluß irgendwelcher äußerer Einwirkungen — etwa auffallenden Lichtes oder auftreffender Elektronenstöße — so liefert die Rechnung ein Ergebnis, das wir keinesfalls nach klassischem Schema so verstehen können, daß bei bestimmten Werten der Phasenkonstanten des Atoms ganz bestimmte Ereignisse eintreten. Sondern das Ergebnis der Rechnung kann nur so gedeutet werden: Es besteht eine angebbare Wahrscheinlichkeit dafür, daß das Atom dieses tut, und es besteht eine angebbare Wahrscheinlichkeit dafür, daß es etwas anderes tut.

Ähnlich verhält es sich mit der Optik. Die klassische Theorie der Optik liefert ja alle Interferenzversuche in einwandfreier Übereinstimmung mit der Wirklichkeit. Aber wenn die Rechnung eine bestimmte Intensität des Lichtes an einem gewissen Orte ergibt, so bedeutet das nicht, daß wirklich eine genau entsprechende Energiemenge dort abgeliefert werden muß. Sondern das klassische Wellenfeld bedeutet lediglich eine gewisse Wahrscheinlichkeit dafür, daß dort Lichtquanten



ankommen. Und man kann bekanntlich auch zu einem Strahl von materiellen Korpuskeln einen undulatorischen Strahl hinzukonstruieren, der sich in gewisser Hinsicht zu den Korpuskeln genau so verhält wie der undulatorische Lichtstrahl zu den dahinfliegenden Lichtquanten. Auch dabei zeigt sich wie überall die rein statistische Natur der bis jetzt bekannten quantenmechanischen Gesetze.

Wir wollen also unsere Aufmerksamkeit nicht auf die diskreten, unstetigen Einzelzustände und Einzelprozesse richten, sondern nur auf die für sie bestehenden Wahrscheinlichkeiten. Mit diesen Wahrscheinlichkeiten sind nun wieder stetig veränderliche Größen in die Beschreibung der physikalischen Wirklichkeit eingeführt, und wir sind damit in einem ganz grundsätzlichen Punkte der klassischen, stetigen Beschreibungsweise formal wieder nähergekommen. Es liegt deshalb die Vermutung nahe, daß für die stetig veränderlichen Wahrscheinlichkeitsgrößen ein Kausalitätsgesetz ähnlich dem früher formulierten Kausalitätsgesetz der klassischen Feldstärken bestehen könnte. Das ist nun in der Tat der Fall — allerdings in einer abstrakteren Weise als in der klassischen Theorie.

Wie Sie wissen, ist SCHRÖDINGER auf einem eigenen, unabhängigen Wege zu einer Formulierung der Quantenmechanik gelangt, die sich als mathematisch als gleichbedeutend mit der aus HEISENBERGS Ideen entwickelten Matrizentheorie erwiesen hat. Er hat mathematische Zusammenhänge der Quantenmechanik aufgedeckt, die zwar infolge der mathematischen Äquivalenz beider Theorien im Grunde genommen schon in der Matrizentheorie enthalten waren, deren explizite Aufstellung aber eine ganz fundamentale Bereicherung der Quantenmechanik bedeutet.

SCHRÖDINGER hat außerdem versucht, im Anschluß an seine Formeln eine neue physikalische Grundlage der Quantentheorie zu entwickeln, wobei er sich zu den von PLANCK, EINSTEIN, BOHR entwickelten Grundvorstellungen der Quantentheorie — stationäre Zustände, Quantensprünge usw. — in radikalen Gegensatz gesetzt hat. Er hat versucht, auf quasiklassische Vorstellungen zurückzukommen, in denen keinerlei Unstetigkeiten mehr auftraten — in denen also auch das Kausalitätsprinzip wieder in klassischer Form gelten kann. Aber diese SCHRÖDINGERschen Spekulationen haben die einmütige Ablehnung aller anderen an der Entwicklung der Quantenmechanik beteiligten Verfasser gefunden. Es ist uns nicht zweifelhaft erschienen, daß die neuen SCHRÖDINGERschen Begriffe ihre physikalische Deutung im engsten Anschluß an die alten Vorstellungen der stationären Zustände und Quantensprünge und die von HEISENBERG eingeführten Gedanken erhalten müssen, daß also die SCHRÖDINGERschen Gesetzmäßigkeiten gleich den matrizentheoretischen Gesetzen statistisch aufgefaßt werden müssen, wie schon vorhin erläutert wurde. Eine solche statistische Auffassung der SCHRÖDINGERschen Theorie ist in sehr klarer und eindrucksvoller Weise von BORN präzisiert worden, auf dessen Überlegungen ich mich in den folgenden Betrachtungen stützen kann.

Der wesentliche Inhalt der SCHRÖDINGERschen Entdeckung ist bekanntlich folgender: Man kann die Gesetze der Quantenmechanik, die in der Matrizentheorie mit Hilfe der transzendenten Algebra, als Systeme von unendlich vielen Gleichungen mit unendlich vielen Unbekannten formuliert wurden, statt dessen auch durch ganz gewöhnliche Differentialgleichungen ausdrücken. Hierdurch ist formal eine große Annäherung an die klassische Theorie zurückgewonnen. Die Frage, wie es möglich sei, in dem unstetigen Gewirr der atomaren, quantenhaften Prozesse etwas mit Differentialgleichungen zu beschreiben, beantworten wir mit BORN so: Die Funktion, welche der Differentialgleichung genügen soll, ist eben die Wahrscheinlichkeitsfunktion.

Wir wollen nun diese Wahrscheinlichkeitsfunktion etwas näher betrachten und uns dabei auch ihre Analogie zu klassischen Verhältnissen deutlich machen. Es möge ein aus zwei Massenpunkten mit den rechtwinkligen Koordinaten $x_1$, $x_2$ bis $z_1$, $z_2$ bestehendes mechanisches System betrachtet werden, das also 6 Freiheitsgrade besitzt. Wir konstruieren uns jetzt etwas Ähnliches, wie den in der statistischen Mechanik betrachteten Phasenraum des Systems; nämlich den Koordinatenraum, welcher jedoch nur halb soviel Dimensionen besitzt, wie der Phasenraum. In unserem Beispiele ist es ein 6-dimensionaler Raum mit den Koordinaten $x_1$ bis $z_2$. In diesem Koordinatenraum wird das System, wenn es bestimmte Koordinaten, aber beliebige Impulse besitzt, durch einen bestimmten Punkt dargestellt, den wir als den Systempunkt bezeichnen wollen. Nach der klassischen Mechanik würde dieser Systempunkt dann im Koordinatenraum eine gewisse Bahn beschreiben. Wir können aber, wenn wir ihn zu einer bestimmten Zeit an einem bestimmten Ort im Koordinatenraume finden, nicht im voraus wissen, wie er laufen wird, weil wir ja aus dem Orte des Systempunkts nur die Koordinaten und nicht die Impulse unserer zwei Massenpunkte erkennen. Sondern man kann nur die Wahrscheinlichkeit dafür bestimmen, daß der Punkt von einem Orte aus in einer gewissen Richtung weiterlaufen wird.

Freilich können wir in der klassischen Mechanik sofort diese statistische Aussage zu einer exakten Vorhersage verschärfen, indem wir nicht nur den Ort, sondern auch die Geschwindigkeit unseres Systempunktes beobachten. Aber dies ist genau der Punkt, wo die Quantenmechanik sich anders als die klassische verhält. Wenn an einem quantenmechanischen System gewisse Koordinaten empirisch beobachtbare Größen sind — wobei wir das Wort Koordinaten so allgemein gebrauchen, daß z. B. auch die Energie oder die Quantenzahlen Koordinaten sind — dann sind die zu diesen Koordinaten gehörigen Impulse

immer gerade prinzipiell unbeobachtbare Größen[1]). Wir können deshalb nur die vorhin formulierte statistische Frage der klassischen Mechanik in die Quantenmechanik übertragen und ihre Beantwortung wahrscheinlich aus der SCHRÖDINGERschen Differentialgleichung herleiten. Ich muß dabei „wahrscheinlich" sagen, weil diesbezügliche Überlegungen noch nicht abgeschlossen sind.

Aber man kann die folgende Frage, die mit der eben erörterten eng verwandt ist, wohl als durch Überlegungen von BORN und PAULI zuverlässig beantwortet ansehen. Wenn wir von unserem System die Energie oder die Quantenzahlen kennen oder noch allgemeiner: Wenn wir wissen, das System hat eine gegebene Wahrscheinlichkeit, im ersten Quantenzustand zu sein; und eine gegebene Wahrscheinlichkeit, im zweiten Quantenzustand zu sein; und so fort. Wie groß ist dann die Wahrscheinlichkeit dafür, daß der Systempunkt im Koordinatenraume der rechtwinkligen Koordinaten $x_1$ bis $z_2$ gerade an einer bestimmten Stelle sitzt? Diese Frage ist sofort zu beantworten, wenn man die SCHRÖDINGERsche Wellenfunktion im Koordinatenraume kennt.

Diese SCHRÖDINGERsche Funktion, die also eine Funktion der 6 Veränderlichen $x_1$ bis $z_2$ ist und außerdem noch von der Zeit abhängt, genügt der fundamentalen von SCHRÖDINGER angegebenen Differentialgleichung. Und man kann nun von dieser Wahrscheinlichkeitsfunktion wiederum die Gültigkeit eines exakten Kausalitätsprinzips behaupten. Man muß dazu jedoch naturgemäß nicht einen Kasten im gewöhnlichen dreidimensionalen Raume betrachten, sondern eben einen 6-dimensionalen Kasten im 6-dimensionalen Koordinatenraum. Dann ist die Formulierung des Kausalitätsprinzips wörtlich dieselbe wie in der klassischen Physik; an Stelle der Ausmessung von elektrischen Feldstärken usw. im Innern und an der Oberfläche des Kastens tritt jedoch die Ausmessung der SCHRÖDINGERschen Wahrscheinlichkeitsfunktion.

Wenn wir also zusammenfassen: Die klassische Feldphysik beschrieb die Welt durch in einem 3-dimensionalen Raume stetig ausgebreitete und mit der Zeit stetig bewegte physikalische Größen. Die Quantenmechanik beschreibt die Welt mit Hilfe eines abstrakten Koordinatenraumes, der ungeheuer viele Dimensionen besitzt: Die Anzahl der Dimensionen ist proportional der Anzahl aller in der Welt vorhandener Materieteilchen. In diesem abstrakten Raume bewegen sich wiederum stetig ausgebreitete Größen, die aber nicht unmittelbar das Einzelgeschehen in der atomaren Erscheinungswelt beschreiben, sondern nur die Wahrscheinlichkeiten quantenhafter Prozesse bestimmen. Die Kausalität — nicht als ein metaphysischer Gegensatz zu einem metaphysischen Zufallsbegriff aufgefaßt, sondern als die früher formulierte physikalische Aussage verstanden — gilt in formal völlig gleicher Weise für beide Theorien.

Man kann natürlich aus dem abstrakten Koordinatenraume wieder in den gewöhnlichen dreidimensionalen Raum zurückkehren, aber man erhält dann eine sehr verwickelte Formulierung des quantenmechanischen Kausalitätsprinzips — denn die Betrachtung des vieldimensionalen Koordinatenraumes ist eben die dem Problem am besten angemessene. Man kann aber doch wenigstens sehen, daß diese verwickelte dreidimensionale Formulierung ungefähr das bedeutet, was ich früher ganz roh und unexakt gesagt habe: daß im Mittel auch die alte dreidimensionale Kausalität erhalten bleibt.

Wir haben gesehen, wie man durch Betrachtung von Mittelwerten und Wahrscheinlichkeiten die elementaren Unstetigkeiten im physikalischen Geschehen eliminieren und Zusammenhänge finden konnte, die mathematisch zu erfassen waren durch ähnliche Methoden wie die von vornherein stetigen Größen der klassischen Physik. Die Quantenmechanik zeigt sich hier ganz als quantitative Verschärfung des Korrespondenzprinzipes von BOHR, der stets, im Gegensatze zu der oft vertretenen Ansicht von der ausschließlichen Herrschaft ganzer Zahlen, daran festgehalten hat, daß man danach streben müsse, durch Mittelwertsbetrachtungen eine formale Analogie zu den klassischen Gesetzen wiederzugewinnen.

Wir wollen uns aber nun von der Betrachtung der stetigen Mittelwerte wieder zurückwenden zu den unstetigen Einzelprozessen. Und wir wollen uns die Frage vorlegen, was man denn nun, nachdem alle irgendwie zu formulierenden Mittelwertsprobleme im Prinzip beantwortet sind, über die Einzelprozesse aussagen kann. Die Beantwortung dieser Frage ist gar nicht so einfach, wie man zunächst glauben möchte, und ich würde mich einer sehr leichtfertigen Behandlung meines Themas schuldig machen, wenn ich nicht wenigstens hinweisen wollte auf die Schwierigkeiten, die dabei auftreten.

Wir wollen zunächst einmal die empirische Seite der Sache betrachten. Man könnte vielleicht denken, daß auch das Experiment in keinem Falle etwas anderes als Mittelwerte zu liefern vermag. Viele von Ihnen werden im letzten Sommer den schönen Vortrag gehört haben, den Herr ZERNICKE über die BROWNsche Bewegung und insbesondere über Arbeiten des Schweden ISING hier gehalten hat, und der uns in so lebhafter und anschaulicher Weise unüberwindliche Grenzen aufgezeigt hat, welche der fortschreitenden Verfeinerung der physikalischen Meßtechnik gesetzt sind. Es ist unmöglich, die Meßgenauigkeit beispielsweise eines Galvanometers über eine gewisse angebbare Grenze hinaus zu steigern; es ist unmöglich wegen der BROWNschen Bewegung in allen Teilen der Apparatur. Die Nadel, der Aufhängefaden, das Gehäuse und die umgebende Luft bestehen aus Atomen, die unausgesetzt in unregelmäßiger, unkontrollierbarer thermischer Bewegung begriffen sind; und der Strom, der durch das Galvanometer fließt, besteht aus einzelnen Elektronen und zeigt deshalb unregelmäßige, nur statistisch berechenbare Schwankungen seiner Intensität, welche die Leistungsfähigkeit des Apparates in ganz derselben Weise begrenzen. Wenn man bedenkt, daß dasselbe bei allen unseren physikalischen Apparaten der Fall ist, daß alle unsere Meßinstrumente thermisch zittern und wackeln, so möchte man leicht glauben, daß der Experimentator über Zustände und Prozesse einzelner Atome grundsätzlich ebensowenig etwas feststellen könnte, wie die Quantenmechanik theoretische Vorhersagen dafür zu machen weiß. Aber es gibt doch ein radikales Mittel, die BROWNsche Bewegung der Apparaturen zum Stillstand zu bringen. Das einfache Rezept, welches der Theoretiker dem Experimentator dafür geben kann, ist dieses: Mache deine Experimente beim Nullpunkt der absoluten Temperatur! Und glücklicherweise haben die Experimentalphysiker noch ein anderes Rezept gefunden, welches in seiner Durchführung nicht ganz so unangenehm, im Grunde genommen jedoch dem ersten gleichwertig ist. Es lautet: Arbeite mit wenigen sehr energiereichen Teilchen! Verglichen mit der Energie eines schnellen $\alpha$-Teilchens ist die thermische Energie der Atome ringsum verschwindend klein, das thermische Gewimmel dieser Atome stört nicht mehr. Und bekanntlich können wir nun, hauptsächlich dank C. T. R. WILSONS grundlegenden Untersuchungen, wirklich das Schicksal eines einzelnen $\alpha$-Teilchens empirisch erkennen, seine Bahn verfolgen und den Zeitmoment des Quantensprunges messen, mit dem sie endigt.

Es gehören also unter Umständen die Zeitmomente einzelner Quantensprünge durchaus zu den empirisch faßbaren Größen, und es fragt sich, was die Theorie nun über diese Zeitmomente auszusagen weiß. Die einfachste und nächstliegende Antwort ist offenbar diese. Die Theorie liefert uns Mittelwerte, sie sagt, wie viele Quantensprünge in einer gewissen Zeit im Mittel über viele Einzelexperimente geschehen müssen. Folglich — so muß man schließen — liefert die Theorie für den einzelnen Quantensprung eine Wahrscheinlichkeit dafür, daß er zu einer vorgegebenen Zeit stattfindet. Und folglich — so möchte man jetzt noch weiter schließen — ist der exakte Augenblick für das Eintreten des Quantensprunges wirklich undeterminiert, und stets existiert nur eine Wahrscheinlichkeit für den Quantensprung. Aber dieser letzte Schluß ist in Wirklichkeit nicht mehr eine notwendige Folgerung aus dem Vorhergehenden; sondern es ist eine darüber hinausgehende Hypothese. Es ist diejenige Hypothese, welche BOHR, KRAMERS und SLATER in ihrer Strahlungstheorie durchzuführen suchten. Diese Forscher haben auch klar erkannt, daß diese Hypothese zu einer ganz bestimmten Folgerung führen mußte, nämlich zu der Folgerung einer nur statistischen Gültigkeit des Energiesatzes. Diese Folgerung ist bekanntlich durch glänzende Experimente von BOTHE und GEIGER und von COMPTON widerlegt worden. Wir können heute ganz bestimmt behaupten: Wenn ein Atom mit einem Quantensprunge Licht entsendet und dieses Licht, ohne durch Interferenzen an seiner geradlinigen Ausbreitung gehindert zu sein, von einem anderen Atome absorbiert wird, dann folgt der Quantensprung des absorbierenden Atoms auf den des emittierenden in einem zeitlichen Abstand, der genau dem räumlichen Abstand der Atome entspricht. Wir sehen also, daß die Zeitmomente von Quantensprüngen jedenfalls nicht immer undeterminiert sind.

Man könnte vielleicht nun versuchen, zu sagen: Die Zeitmomente von Quantensprüngen sind determiniert, soweit der strenge Energiesatz es verlangt, sonst undeterminiert. Aber diese etwas doppelzüngige Erklärung ist doch zu unbestimmt, als daß man etwas damit anfangen könnte, sobald z. B. durch Interferenzen verwickeltere Verhältnisse eintreten. Ein anderer naheliegender Weg zur Überwindung dieser Schwierigkeiten ist schon vor längerer Zeit von WENTZEL versucht worden: Da der Absorptionsakt in unserem eben besprochenen Beispiel vollkommen determiniert ist durch den vorangehenden Emissionsakt, so könnte man beide zusammen als einen einzigen quantentheoretischen Elementarakt betrachten und dann hoffen, daß derartige Elementarakte voneinander statistisch unabhängig sind. Es scheint jedoch, daß man auch auf diesem Wege nicht zu einfachen Formulierungen gelangt.

Es ist nun sehr bezeichnend, daß in den vorhin erläuterten BORN-PAULIschen Formulierungen in der Tat nicht etwas über die Wahrscheinlichkeit eines Quantensprunges ausgesagt wurde — wir haben ja gerade gesehen, daß das nicht zu unabhängigen Wahrscheinlichkeiten führen könnte — sondern über Wahrscheinlichkeiten dafür, daß der Systempunkt sich an einem bestimmten Ort im Koordinatenraum befindet. Man kann also vielleicht hoffen, daß diese Überlegungen uns wirklich zu unabhängigen physikalischen Elementarwahrscheinlichkeiten führen werden.

Nämlich, obwohl wir nach der Quantenmechanik alle möglichen Wahrscheinlichkeiten im Prinzip berechnen können, bleibt doch noch ein wesentliches Problem ungelöst. Wir wollen der Deutlichkeit halber ein kleines Beispiel betrachten. Wir wollen würfeln mit zwei Würfeln, und es möge sich dabei empirisch ergeben, daß im Mittel eine 1 mit einer 3 ebenso häufig oben ist wie eine 4 mit einer 5 und doppelt so häufig wie zwei Zweien usw. Wenn wir nun eine Theorie hätten, die in irgendeiner ganz verwickelten und abstrakten Weise diese empirischen Tatsachen vorauszuberechnen erlaubte, dann könnten wir ja vielleicht zufrieden sein. Aber in Wirklichkeit sind wir doch erst dann zufrieden, wenn wir die Theorie in folgende Form gebracht haben: Wir sagen, für einen der Würfel

[1]) Dabei ist es möglich, mit verschiedenen experimentellen Anordnungen verschiedene Koordinaten zu beobachten; aber bei einer bestimmten Anordnung kann man bestenfalls gewisse, bestimmte Koordinaten eines Atoms exakt beobachten, während dann in dieser Versuchsanordnung die zugehörigen Impulse gerade nicht exakt beobachtbar sind.

ist jede seiner 6 Lagen gleichwahrscheinlich; und die beiden Würfel sind voneinander statistisch unabhängig. Nur wenn wir die Sache so ansehen, glauben wir, daß wir sie wirklich verstanden haben.

Nun ist es bei den zwei Würfeln freilich so, daß man von vornherein gar nicht darauf kommt, die Theorie anders zu machen, als eben geschildert wurde. Aber in der Quantenmechanik ist es anders: In der Quantenmechanik können wir gegenwärtig alle Wahrscheinlichkeiten berechnen; aber wir können sie noch nicht verstehen! Wir würden erst dann behaupten können, sie verstanden zu haben, wenn wir die mathematischen Rechnungen, die im abstrakten Koordinatenraum ausgeführt werden, folgendermaßen deuten könnten: In gewissen Fällen gibt es keine Vorschrift für das, was die Natur tut; sie kann das eine oder das andere tun, beides ist gleichwahrscheinlich. Und die Entscheidung, welche die Natur in einem solchen Falle trifft, ist völlig unabhängig von den Entscheidungen, die sie in anderen Fällen getroffen hat.

Mit anderen Worten gesagt: Wir müssen die Wahrscheinlichkeiten, die uns von der Quantenmechanik quantitativ geliefert werden, zurückführen auf unabhängige Elementarwahrscheinlichkeiten. Erst dann werden wir behaupten können, diese Gesetze wirklich verstanden zu haben; erst dann werden wir entscheiden können, unter welchen Bedingungen und in welcher Weise der Zeitmoment eines Quantensprunges determiniert und wann er nicht determiniert ist. Erst dann werden wir genau übersehen, was im physikalischen Geschehen kausal bestimmt, und was dem Zufall überlassen ist.

Zum Schluß möge nun aber noch ein Umstand besonders hervorgehoben werden. Wir haben es soeben als schon gesichert betrachtet, daß die noch durchzuführende Elementaranalyse der quantenmechanischen Wahrscheinlichkeitsgesetze zu dem Ergebnis führen müßte, daß gewisse Elementarprozesse undeterminiert seien und jeweils gleichwahrscheinlich in verschiedener Art stattfinden könnten. Aber das ist in Wahrheit noch durchaus keine Selbstverständlichkeit. Der Umstand, daß die Gesetze der Quantenmechanik Mittelwertsgesetze sind und nur unter Vermittlung statistischer Begriffe auf die Elementarprozesse angewandt werden können, liefert an sich noch keinen zwingenden Grund dafür, daß auch die Elementargesetze Wahrscheinlichkeitsgesetze sein müßten.

Wir können also unsere Frage, ob die heutige Physik den Determinismus anerkennt — eine Frage, von der wir gesehen haben, daß sie bei näherer Betrachtung in mehrere verschiedene Fragen aufzulösen ist — zum letzten Male jetzt in folgender Form stellen: Werden die gesuchten Elementargesetze Wahrscheinlichkeitsgesetze oder determinierende Gesetze sein? Wird es überhaupt vorkommen, daß der Zeitmoment eines einzelnen Quantensprunges undeterminiert ist?

Vermutlich wird es wohl so sein, daß in der Tat unvollständige Determinierungen, also reine Wahrscheinlichkeiten in den physikalischen Elementargesetzen stecken. Aber, wie gesagt, eine zuverlässige Entscheidung wird erst nach einer weiteren Analyse der Quantenmechanik in der von BORN und PAULI gewiesenen Richtung möglich sein. Und vielleicht darf ich zum Schluß noch erwähnen, daß diesbezügliche Überlegungen in allerletzter Zeit in Kopenhagen und hier in Göttingen in, wie ich glaube, aussichtsreicher Weise weitergeführt werden konnten.

überreicht vom Verfasser

# Ueber den Mechanismus der Verdampfung und Kondensation

von

**Dr. J. Estermann, Hamburg**

Mit 4 Figuren im Text

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# Ueber den Mechanismus der Verdampfung und Kondensation

von

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Die Vorgänge an Grenzflächen sind in den meisten Fällen so komplizierter Natur, daß es bisher nicht möglich war, die ihnen zu Grunde liegenden einfachen Gesetzmäßigkeiten aufzufinden. Die einzigen Fälle, die man in reinem Zustand und unter einfachen Bedingungen beobachten kann, sind die Verdampfung bzw. Kondensation eines reinen Stoffes und die Abscheidung aus dem Dampfzustand an einer reinen Grenzfläche.

Während nun aber die Gleichgewichtsverhältnisse bei diesen Vorgängen an der Phasengrenzfläche sowohl experimentell wie auch theoretisch als genügend geklärt angesehen werden können, ist über diejenigen Vorgänge, die zur Einstellung des Gleichgewichts führen, also über den Mechanismus des Molekülaustausches[1]) und seinen zeitlichen Ablauf noch sehr wenig bekannt. Es sind jedoch schon verschiedene Vorstöße zur Klärung dieser Fragen gemacht worden, und über diese soll im Folgenden zusammenfassend berichtet werden.

Zunächst sei als einfachster und sauberster Grenzflächenvorgang die Verdampfung eines festen kristallinen Körpers ins Vakuum und ihre Umkehrung, die Kondensation betrachtet. Zur Ableitung der Dampfdruckformel mit Hilfe der Thermodynamik braucht man bekanntlich über diesen Vorgang nichts weiter vorauszusetzen, als daß er reversibel geleitet werden kann. Um Näheres über den Mechanismus zu erfahren, muß man also andere, außerhalb der Thermodynamik liegende Überlegungen anstellen.

Durch die Beobachtung des Kondensationsvorgangs[2]) gelang es zuerst, Näheres über den Mechanismus des Molekülaustausches zwischen der festen und der Gasphase zu ermitteln. Wenn sich ein Kristall im übersättigten Dampf bildet, so beobachtet man häufig, z. B. bei Quecksilber, daß diese Kristalle Blättchen- oder Nadelform zeigen, daß also eine Richtung viel stärker oder viel schwächer ausgebildet ist als die beiden anderen. Eine solche Kristallform kann nur dadurch entstehen, daß die Kristalle in den verschiedenen Richtungen sehr verschieden schnell wachsen. (Die mehrfach geäußerte Anschauung, daß diese Abweichung der Kristalle von der Kugelgestalt davon herrührt, daß die verschiedenen Kristallflächen infolge der Unterschiede der Oberflächenspannung für die einzelnen Gitterebenen verschiedenen Dampfdruck zeigen, läßt sich nicht aufrecht erhalten, da man das Wachstum der Metallkristalle in übersättigtem Dampf soweit von Gleichgewicht entfernt erfolgen lassen kann, daß die Wiederverdampfung zu vernachlässigen ist.) Die Verschiedenheit der Wachstumsgeschwindigkeiten hat man nun folgendermaßen zu erklären versucht: zunächst treffen auf alle Kristallflächen aus dem Dampfraum gleich viel Moleküle pro Flächeneinheit auf. Es werden aber nicht alle Moleküle angelagert, sondern es wird nur ein Bruchteil kondensiert und der Rest wieder reflektiert. Ist der kondensierte Bruchteil für eine bestimmte Fläche groß, so wächst die dazu senkrechte Fläche sehr schnell und umgekehrt. Mit Hilfe dieser Unterschiede des „Kondensationskoeffizienten“ $\alpha$ kann man zwar qualitativ die Bildung von Kristallen erklären, jedoch versagt diese Begründung bei der quantitativen Betrachtung. Es wurde nämlich einerseits beobachtet, daß bei den sich beim Quecksilber bildenden hexagonalen Blättchen der Durchmesser die Dicke um das $10^4$fache übertrifft, während andererseits direkte Messungen der Größe $\alpha$ ergaben,[3]) daß sie beim festen Quecksilber im fraglichen Gebiet nur etwa 0,9 beträgt. Die auffallend großen Unterschiede in der Wachstumsgeschwindigkeit lassen sich also durch den Kondensationskoeffizienten allein ebenfalls nicht erklären.

[1]) Es soll im Folgenden auch dann von Molekülen gesprochen werden, wenn es sich um Atome oder Ionen handelt.

[2]) M. Volmer und J. Estermann, Zeitschrift für Physik 7, 13, 1921.

[3]) M. Knudsen, Ann. d. Physik 50, 472, 1916; M. Volmer und J. Estermann, Zeitschr. für Phys. 7, 1. 1921.

Nun kann man jedoch die maximale Wachstumsgeschwindigkeit (keine Reflexion, $\alpha=1$) mit Hilfe der kinetischen Gastheorie ermitteln. Man braucht nur die Zahl der Moleküle auszurechnen, die auf die Oberflächeneinheit bei einem bestimmten Dampfdruck auftreffen. Die Beobachtung ergab aber, daß das Breitenwachstum der Quecksilberkristalle etwa tausendmal so groß ist als die mit dem betreffenden Dampfdruck berechnete maximale Wachstumsgeschwindigkeit. Es müssen also an die zur schnellwachsenden Kristallfläche a senkrecht liegenden Flächen b (Fig. 1) (Seitenflächen des hexagonalen Prismas) viel mehr Moleküle

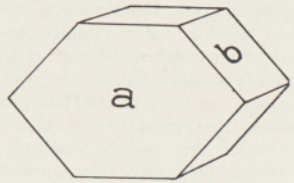


Fig. 1.

angelagert werden als aus dem freien Gasraum auf diese Flächen auftreffen. Es sind dies also auch diejenigen Moleküle, die auf die schnell wachsende Grundfläche a auffallen. Da diese Fläche a, sobald der Kristall etwas gewachsen ist, sehr viel größer ist als die Flächen b, so kann sie dann sehr schnell wachsen, wenn auch alle oder fast alle auf die Fläche a auftreffenden Moleküle nicht an dieser, sondern an den Flächen b angelagert werden. Man muß sich also den Mechanismus der Kondensation so vorstellen, daß die aus dem Gasraum auf die schnell wachsende Fläche a auftreffenden Atome nicht gleich in den Gitterverband eintreten, sondern zunächst adsorbiert werden und gewissermaßen auf der Fläche umhergleiten, bis sie an einen Platz kommen, auf dem sie angelagert werden können. Solche Plätze sind nun offenbar auf der großen Fläche nur sehr wenige vorhanden, denn wie die Beobachtung der Wachstumsgeschwindigkeit ergibt, werden fast alle diese Moleküle von der Fläche a abrutschen und auf eine der Flächen b gelangen, wo sie angelagert werden können. Der Übergang aus der Gas- in die feste Phase erfolgt somit nicht direkt, sondern unter Vermittlung eines Zwischenzustandes, den man als Adsorptionszustand oder als eine Art „zweidimensionales" Gas bezeichnen kann. Da dieser Zustand isotrop ist und man wohl annehmen kann, daß die Verdampfung der Kristalle auch über diesen Zwischenzustand erfolgt, so erledigt sich mit diesem Befund auch eine von Knudsen[1]) und von Volmer[2]) aufgeworfene Frage nach der Richtung der aus dem Kristall bei der Verdampfung austretenden Moleküle dahin, daß der Übertritt in die Gasphase in Bezug auf die Richtung nach den Wahrscheinlichkeitsgesetzen erfolgt, daß also keine Richtung bevorzugt wird.

Nun ist jedoch noch ein weiterer Befund zu erklären. Wenn die Kristalle nämlich einen Durchmesser von etwa 0,3 mm erreicht haben, so hört das Breitenwachstum allmählich auf und das Dickenwachstum nimmt entsprechend zu, so daß die Kristalle sich im Laufe der Zeit immer mehr der Kugelform annähern. Wir schließen daraus, daß die absorbierten Moleküle nur über eine gewisse Strecke rutschen können, d. h. sie können nur dann von der Fläche a auf die Seitenflächen b gelangen, wenn der dabei zurückzulegende Weg etwa von der Größenordnung 0,1 mm ist. Kommt das Molekül inzwischen nicht auf die andere Fläche, so kann es entweder verdampfen (die auf diese Weise verdampfenden Moleküle ergeben den beobachteten Reflexionskoeffizienten $1-\alpha = 0{,}1$) oder aber mit einem zweiten Molekül zusammenstoßen. Ein solcher „Zwilling" hat dann eine geringere Beweglichkeit, lagert sich an eine

[1]) M. Knudsen, Ann. d. Physik 52, 105, 1917.
[2]) M. Volmer, Zeitschrift für Physik 5, 31, 1921.



Gleichgewichtslage und bildet so den Keim zu einer neuen Netzebene, die sich jetzt scheibenartig auf die vorher bestehenden legt. Ist der Kristall noch klein, so wird die Anlagerung an der Seite (das Abrutschen) überwiegen, während bei größeren Kristallen die Wahrscheinlichkeit für die Bildung neuer Netzebenen größer ist. Der „Scheibenaufbau" kann häufig noch bei fertigen Kristallen beobachtet werden.

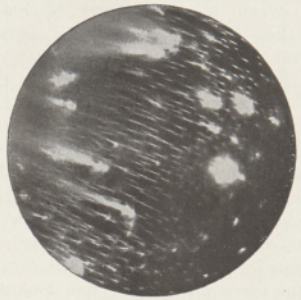

Fig. 2.

Wir wollen nunmehr die Kondensation eines Metalldampfs an einer fremden gekühlten Oberfläche z. B. an einer Glasfläche, betrachten. Wir werden auch in diesem Falle mit Langmuir[1]) zunächst annehmen, daß die aus dem Gasraum kommenden Metallatome an der Glasfläche adsorbiert werden. Sie bleiben jedoch nicht auf dem Platz liegen, wo sie auftreffen, sondern können auf der Glasfläche eine zeitlang ihre Wärmebewegung fortsetzen und dann, genau wie im ersten Fall wieder verdampfen oder mit anderen zusammenstoßen.[2]) Ein Abrutschen auf eine andere Kristallfläche kann hier selbstverständlich nicht stattfinden. Ist die Temperatur der Fläche genügend tief, so ist der Fall der Wiederverdampfung, wie Knudsen[3]) gezeigt hat, auszuschließen. Die Atome werden sich also solange hin und her bewegen, bis zwei zusammenstoßen, dazu kommt dann ein drittes und schließlich bildet sich ein Kriställchen aus. Je größer das entstandene Aggregat ist, desto geringer wird seine Beweglichkeit, bis sie schließlich aufhört. Ist die Anzahl der insgesamt auftreffenden Atome so gering, daß nur eine einatomige Schicht entstehen könnte (oder noch geringer), so wird der erhaltene Niederschlag trotzdem aus von einander getrennten größeren Metallkristallen bestehen, da ja die Atome nicht einfach am Orte ihres Auftreffens liegen bleiben, sondern sich solange hin und her bewegen, bis eine größere Anzahl zu einem Kristall zusammengetreten ist. Mit Hilfe einer ultramikroskopischen Anordnung kann man diese Erscheinung sichtbar machen.[4]) Fig. 2[5]) zeigt in ultramikroskopischer Photographie eine durch Kondensation aus dem Dampf auf einer Quarzplatte erzeugte Silberschicht von der Dicke von etwa $3.10^{-9}$ cm, also $^1/_{10}$ Atomschicht; Fig. 3 den Rand einer etwas dickeren Schicht. Die größeren Flecken auf den Aufnahmen sind Staubkörnchen. Die Einzelkristalle sind sehr deutlich erkennbar, man sieht auch, daß sie verhältnismäßig weit auseinander liegen. Da zur ultramikroskopischen Aufnahme ein gewöhnlicher Dunkelfeldkondensor benutzt wurde, so müssen die Einzelkristalle, um sichtbar zu

[1]) J. Langmuir, Phys. Rev. 8, 149, 1916.
[2]) Auf dieser Grundlage hat J. Frenkel eine ausführliche Theorie der Adsorption und Kondensation durchgeführt (Zeitschrift für Physik 26, 117, 1924).
[3]) M. Knudsen, Ann. d. Physik 50, 472, 1916.
[4]) J. Estermann, Zeitschrift für physik. Chemie 106, 403, 1923.
[5]) Fig. 2 und 3 stammen aus W. Gerlach, Atomstrahlen (Ergebnisse der exakten Naturwiss. II), Fig. 4 aus einer Arbeit des Verf. (Zeitschrift für Physik XXXIII, 4). Dem Verlage J. Springer, Berlin, sei auch an dieser Stelle für die bereitwillige Ueberlassung von Galvanos gedankt. — Die Schriftleitung.

sein, mindestens aus etwa tausend Atomen bestehen, während die „mittlere Dichte" der Schicht nur etwa $^1/_{10}$ Atom war. Sie können also nur durch Zusammenrutschen der Einzelatome entstanden sein. Auch andere Beobachtungen bei der Kondensation sprechen dafür, daß sich vor der Bildung der festen Phase erst eine Adsorptionsschicht auf der Unterlage bildet. Wenn nämlich ein Dampfstrahl auf eine gekühlte Fläche trifft, so bildet sich nur dann ein Niederschlag aus, wenn bei bestimmter Strahldichte die Temperatur dieser Fläche unterhalb eines kritischen Wertes liegt.[1]) Bei auch nur wenig höheren Temperaturen entsteht dagegen kein Niederschlag mehr, so daß es den Anschein hat, als ob dann die auftreffenden Atome direkt reflektiert werden. Zur Erklärung dieser Erscheinung[2]) nehmen wir auch hier an, daß alle auftreffenden Moleküle auch dann, wenn kein Niederschlag entsteht, zunächst absorbiert werden. Die Temperatur der Fläche sei jedoch jetzt nicht mehr so tief, daß die Wiederverdampfung, wie im vorigen Fall, auszuschließen ist. Dann bleiben die Moleküle in der Adsorptionsschicht so lange, bis sie entweder wieder verdampfen oder mit anderen zusammenstoßen und einen Kristallkeim bilden, der die Entstehung eines Niederschlages einleitet. Von der mittleren Verweilzeit einerseits und von der Konzentration der Atome in der Adsorptionsschicht andererseits wird es somit abhängen, ob ein Niederschlag entsteht oder nicht. Da man annehmen muß, daß diese mittlere Verweilzeit mit fallender Temperatur stark zunehmen wird, so folgt aus dieser Betrachtung, daß die kritische Kondensationstemperatur von der Intensität des auftreffenden Molekularstrahls (der die Konzentration der Atome in der Adsorptionsschicht proportional ist) in der Weise abhängig sein wird, daß die kritische Temperatur mit zunehmender Dichte des Molekularstrahls immer höher wird.

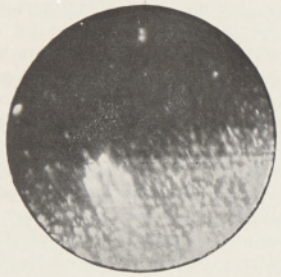

Fig. 3.

Dieser Effekt, der von verschiedenen Seiten qualitativ beobachtet worden ist, wurde nun vom Verfasser[3]) quantitativ in der Weise untersucht, daß ein Molekularstrahl von bekannter variabler Intensität auf eine gekühlte Fläche, deren Temperatur ebenfalls verändert werden konnte, geleitet wurde. Dann konnte beobachtet werden, bei welchen Temperaturen bei den verschiedenen Intensitäten noch gerade ein Niederschlag entstand. Auf diese Weise wurde für verschiedene Systeme, nämlich für Cadmium auf Glas, Silber und Kupfer sowie für Quecksilber auf Silber die kritische Kondensationstemperatur als Funktion der Strahlintensität bestimmt. Macht man nun die unbedenkliche Annahme, daß bei der kritischen Temperatur im Grenzfall ebensoviel Moleküle aus der Adsorptionsschicht wieder verdampfen, wie aus dem Dampfstrahl auftreffen, so kann man aus der bekannten Intensität des Molekularstrahls den

[1]) M. Knudsen, Ann. d. Physik 50, 472, 1916.
[2]) J. Frenkel, a. a. O.
[3]) J. Estermann, Zeitschrift für Elektrochemie 31, 441, 1925; vgl. auch W. Gerlach, Atomstrahlen, Ergebnisse der exakten Naturwissenschaften Bd. III, Berlin 1925.



„Dampfdruck" der Adsorptionsschicht, der als Adsorptionsdruck bezeichnet werden soll, berechnen. Die erhaltenen Ergebnisse sind in Tabelle I enthalten.

**Tabelle I**

Adsorptionsdrucke für Cadmium auf verschiedenen Unterlagen.

| Glas | | Kupfer | | Silber | |
|---|---|---|---|---|---|
| abs. Temperatur | Adsorptionsdruck | abs. Temperatur | Adsorptionsdruck | abs. Temperatur | Adsorptionsdruck |
| 166° | $13 \cdot 10^{-8}$ | 162° | $13{,}2 \cdot 10^{-8}$ | 187° | $13{,}7 \cdot 10^{-8}$ |
| 187 | $49 \cdot 10^{-8}$ | 180 | $31{,}4 \cdot 10^{-8}$ | 199 | $33{,}0 \cdot 10^{-8}$ |
| 210 | $121 \cdot 10^{-8}$ | 190 | $50{,}3 \cdot 10^{-8}$ | 207 | $52{,}3 \cdot 10^{-8}$ |

Zum Vergleich sei erwähnt, daß sich der Dampfdruck für festes Cadmium bei 200° abs. nach der Formel von Braune[1]) zu etwa $3 \cdot 10^{-20}$ mm berechnen würde. Da die Abhängigkeit des Adsorptionsdruckes von der Temperatur sich ganz gut als Exponentialfunktion darstellen läßt, so kann man aus diesen Werten mit Hilfe der Clausius-Clapeyron'schen Gleichung die „Adsorptionswärmen" berechnen und erhält für Cadmium auf Glas etwa 3500 cal/Mol, für Cadmium auf Kupfer etwa 3000 cal/Mol, für Cadmium auf Silber etwa 5000 cal/Mol. Diese Werte entsprechen überschlagsmäßig der Arbeit, die erforderlich ist, um ein Aggregat von zwei Atomen auseinander zu reißen und stützen somit die von Frenkel vertretene Auffassung, daß die Bildung eines „Zwillings" einen wesentlichen Faktor bei der Kondensation darstellt und daß solche zweiatomige Aggregate bereits als Kristallkeime wirken können.

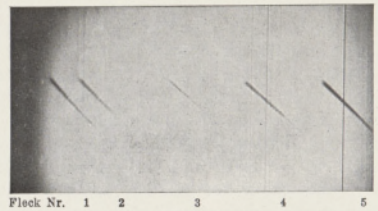


Fig. 4.

In der Nähe der kritischen Kondensationstemperatur macht sich noch ein anderer Effekt bemerkbar, der durch diese Anschauung über den Mechanismus der Kondensation zwanglos erklärt werden kann.[2]) Wenn man den Dampfstrahl durch eine unmittelbar vor der Auffangplatte befindliche Blende begrenzt, so beobachtet man, daß bei Auffangstemperaturen, die nur wenig unter der kritischen Kondensationstemperatur für die betreffende Strahldichte liegen, die Randzone des Niederschlags nicht mit erscheint, während bei genügend starker Kühlung sich der Niederschlag in der vollen Größe der Blendenöffnung ausbildet. In Figur 4 ist eine Photographie solcher Niederschläge von Cadmium auf Glas wiedergegeben. Die Temperatur der Auffangplatte und die Bestrahlungszeiten finden sich in der Tabelle II.

Der der Ofentemperatur von 295° entsprechenden Strahlintensität entspricht bei der benutzten Anordnung eine kritische Kondensationstemperatur von etwa — 90°. Selbst 30° unterhalb dieser Temperatur erscheint also, wie am Fleck Nr. 3 deutlich sichtbar, die Randzone auch nach fünfmal so langer Bestrahlungszeit wie bei Kühlung auf — 180° nicht. Diese Erscheinung

[1]) Landolt-Börnstein, Tabellen, 5. Aufl. Berlin 1925.
[2]) J. Estermann, Zeitschrift für Physik, 33, 320, 1925, vgl. auch W. Gerlach a. a. O.

**Tabelle II**

| Fleck Nr. | Ofen-temperatur ° C | Auffang-temperatur | Bestrahlungs-zeit Minuten |
|---|---|---|---|
| 1 | 295 | — 180 | 3 |
| 2 | 295 | — 180° bis 118° | 4 |
| 3 | 295 | — 118 | 10 |
| 4 | 300 | — 180 | 2 |
| 5 | 300 | — 180 | 3 |

beruht darauf, daß trotz gleichmäßiger Strahldichte die Dichte in der Adsorptionsschicht am Rande der bestrahlten Fläche kleiner ist als in der Mitte, weil dort die Moleküle aus dem Bereich der Blende seitlich abströmen und dadurch für die Keimbildung verloren gehen, während im Innern der bestrahlten Fläche die abströmenden Moleküle wieder durch zuströmende Moleküle ersetzt werden. Infolge der niedrigeren Dichte hat die Randzone auch eine niedrigere kritische Kondensationstemperatur.

Auch folgender von Volmer und Mahnert[1]) beschriebener Versuch illustriert deutlich die freie Beweglichkeit von Atomen in Oberflächen. Berührt man eine saubere Quecksilberoberfläche mit einem Benzophenonkristall, so breitet sich das Benzophenon nach allen Seiten hin aus und bedeckt schließlich das Quecksilber mit einer zusammenhängenden Schicht. Man kann diesen Effekt sichtbar machen, wenn man die Quecksilberoberfläche mit Talkum bestreut; das in die Oberfläche gehende Benzophenon treibt das Talkum an den Rand. Benzophenon ist also in einer Quecksilberoberfläche löslich, während es in flüssigem Quecksilber vollständig unlöslich ist. Volmer und Mahnert haben diese Löslichkeit auch quantitativ bestimmt, und mit Hilfe dieser Löslichkeit haben Volmer und Adhikari[2]) nachgewiesen, daß auch der Abbau der Kristalle unter Vermittlung des adsorbierten Zwischenzustandes erfolgt. Zu diesem Zweck ließen sie auf die Seitenfläche eines nadelförmigen Benzophenonkristalls eine kontinuierliche Folge von Quecksilbertropfen fallen. Die Versuchsanordnung war so eingerichtet, daß die Quecksilbertropfen die Spitze des Kristalls nicht berühren, sondern ihr nur auf einige Zehntel Millimeter nahe kommen konnten. Unter dem Mikroskop konnte man dann beobachten, daß das Benzophenon nicht nur an der Stelle, wo die Quecksilbertropfen es berühren, allmählich verschwindet, sondern daß auch die Spitze der Kristallnadel abgebaut wird. Da die Abbaugeschwindigkeit viel größer ist als die maximale Verdampfungsgeschwindigkeit, so läßt sich dieses Versuchsergebnis nur so deuten, daß die Moleküle aus der Spitze in die auf der ganzen Kristalloberfläche vorhandene Adsorptionsschicht übergehen und von dieser dann auf den Quecksilbertropfen. Sie strömen daher von allen Teilen des Kristalls nach der Stelle ab, wo der Quecksilbertropfen berührt, oder mit anderen Worten gleiten von der Spitze auf der Kristalloberfläche zur Berührungsstelle hin.

Nach den berichteten Versuchen kann wohl als sicher angenommen werden, daß an der Grenze zwischen der festen und der Gasphase sich stets eine Adsorptionsschicht mit frei beweglichen Molekülen befindet, die für den Mechanismus der Verdampfung und Kondensation eine große Bedeutung hat. Über die Art und die Größe der Kräfte, die diese Adsorption bewirken, sowie über die Gleitgeschwindigkeit und damit zusammenhängende Fragen kann zur Zeit noch nichts Näheres gesagt werden, doch werden weitere Untersuchungen hoffentlich in absehbarer Zeit noch neues, wichtiges Material zu Tage fördern.

[1]) M. Volmer und Mahnert, Zeitschrift für phys. Chemie 115, 239, 1925.
[2]) M. Volmer und G. Adhikari, Zeitschrift für Physik 35, 170, 1925.