(d) Under these circumstances it is essential to distinguish between those results of the theory which can be unambiguously computed and those which cannot. In general all the results of the theory which are given by convergent expressions—the energy differences in a given field, the rate of production of pairs, the transition probabilities—are gauge and Lorentz invariant; but this is not true of those predictions which, like the treatment of the (0) state in Section 4, depend essentially on the reaction of pairs of arbitrarily high energy. As is more fully discussed in that section, these divergence difficulties are closely connected with the inadequacy of quantum theoretical field methods when applied to very short lengths, and are of such a character that the predictions of the theory, even if they could be computed unambiguously, could not be unambiguously compared with experiment. It therefore seems possible that no sensible improvement in the theory will be made on the basis of the present quantum theoretical treatment of fields; certainly no obvious changes in the definition of positive and negative states overcome the difficulties here formulated.

(e) We are indebted to Professor Breit for pointing out to us that the proofs leading up to (3.2) and (3.14), which establish the validity of the use of the Dirac equation for computing energy differences and matrix elements, can be greatly simplified. For the formalism on which the proofs are based differs from the quantum mechanical formalism of a many body problem only by the subtraction of the spur (2.26), and in this latter formalism the equalities (3.3) and (3.14) follow directly from the transformation theory. But on the quantities involved here, namely the nondiagonal elements of an operator, and the differences between various diagonal elements, the subtraction of the spur, which in no way involves the dynamical variables of the system, can have no effect.

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February 12, 1934.

The Surface Ionization of Potassium on Tungsten

The surface ionization of alkali metals on W and W—O surfaces partly covered by adsorbed layers of the alkali metal has been investigated by Langmuir[1] and others.[2, 3, 4] The method employed by them involved surrounding the ionization unit with the saturated vapor of the alkali metal. Attempts by these investigators to extend measurements to high temperatures have not been successful because of the onset of large photoelectric currents from collector to wire at about 1500°K.

While observing the scattering of a ray of potassium atoms from a crystal surface, we employed a tungsten wire and collector cylinder as a detector.[1, 5] With the detector surrounded by liquid air, no evidence of a photoelectric current was observed even at high wire temperatures. This suggested the use of a molecular ray method to determine the efficiency of surface ionization of potassium by tungsten at high temperatures.

A potassium ray of constant intensity was allowed to fall upon a clean tungsten wire in an extremely high vacuum, and the positive ion current was measured at several wire temperatures. Without disturbing the ray, the wire was then covered with oxygen, and the positive ion current obtained was assumed[1] to correspond to 100 percent ionization. The circled points in Fig. 1 show the results of an experiment in which the vacuum conditions were unusually good.

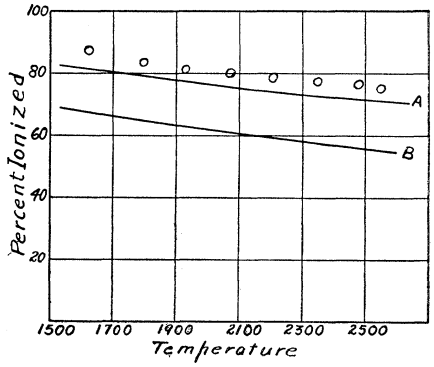

FIG. 1.

The chief interest in the results lies in the fact that all of the preliminary data are clustered about a theoretical curve (Fig. 1, A) calculated by omitting the ratio of statistical weights from the modified Saha equation. This equation may be written

$$\nu_+/\nu_a=(\omega_+/\omega_a)\exp\left[-(I-\phi)\epsilon/kT\right], \qquad (1)$$

in which ν_+ is the number of ions and ν_a the number of atoms of ionization potential I evaporating per second from 1 cm² of a surface of work function ϕ at temperature T; and ω_+ and ω_a are the statistical weights. In calculating theoretical percents ionized, the following values were assumed for the constants: ϕ (tungsten) = 4.52 e. v.; I (potassium) = 4.32 e. v.; and $\omega_+/\omega_a=\frac{1}{2}$. Fig. 1, B gives the theoretical percent ionized as a function of temperature when the statistical weights' ratio $\frac{1}{2}$ is included. It is evident that the experimental results are in better agreement with A than with B. However, there seems to be no justification for the omission of the statistical weights from Eq. (1).

A clue to the cause of the divergence between the experimental points and theory appears when the data are plotted to the axes log (ν_+/ν_a) against $1/T$, as is done in Fig. 2. Since ω_+/ω_a is 0.5, an intercept equal to log 0.5, or

[1] I. Langmuir, Proc. Roy. Soc. **A107**, 61 (1925).
[2] Ives, Phys. Rev. **21**, 385 (1923).
[3] Meyer, Ann. d. Physik (5) **4**, 357 (1930).
[4] Becker, Phys. Rev. **28**, 341 (1926).
[5] Taylor, Zeits. f. Physik **57**, 242 (1929).

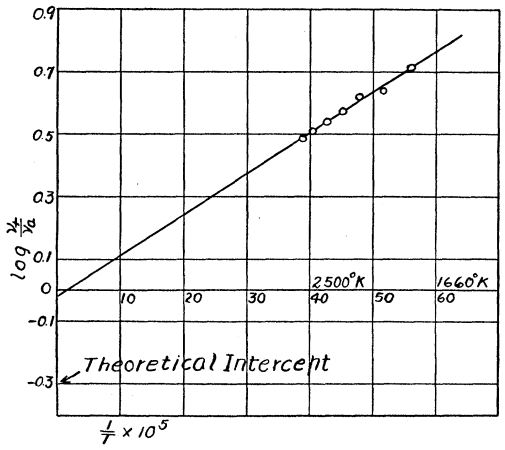

FIG. 2.

-0.30, is to be expected. The experimental data, however, exhibit an intercept of about -0.03. Several other preliminary experiments have led to intercepts which lie both above and below the origin, but within the limits ± 0.1. These observations point to the possibility that a factor, which multiplies the exponential term and cancels at least in part the statistical weights' ratio, has been omitted in Eq. (1). A somewhat more general equation may be written, which contains such a factor, involving reflection coefficients for ions and atoms, namely,

$$\frac{\nu_+}{\nu_a} = \frac{1-r_+}{1-r_a} \cdot \frac{\omega_+}{\omega_a} \exp\left[\frac{-(I-\phi)\epsilon}{kT}\right]. \quad (2)$$

If the ratio $(1-r_+)/(1-r_a)$ were equal to approximately 2, the absence (within experimental error) of an intercept would be accounted for. There are at present no experimental data upon the reflection coefficients of atoms or ions known to the writers. It has been assumed in the past that the ratio $(1-r_+)/(1-r_a)$ is nearly unity.

It may be significant that the dilemma which arises here is very similar to that which arose recently in the case of the thermionic emission of electrons,[6] and which led to the suggestion of a reflection coefficient for electrons of $\frac{1}{2}$. It will be apparent from the discussion above that very careful work would be necessary in order to establish or disprove the existence of zero intercept.

It should be stated here that the above experiment affords a method for the determination of the work function of tungsten independent of thermionic emission. The value of ϕ obtained from the slope in Fig. 2 is 4.56 e.v. Several other determinations have given values ranging from 4.50 to 4.57 e.v.

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[6] See Fowler, *Statistical Mechanics*, p. 268, Cambridge Press (1929).

Gamma-Rays from Carbon Bombarded with Deutons

By using the method previously applied[1] to other elements we have observed a very penetrating radiation from carbon bombarded with deutons, and have attempted to analyze it. We have made measurements of the absorption of this radiation in lead and in paraffin, with two electroscopes, one lined with lead and the other with paraffin. The tube was operated at 900 kilovolts and 10 microamperes ion current. The hydrogen contained about 30 percent H^2. The ions were allowed to impinge alternately on a target of graphite and a target of some heavier element. Aluminum, copper and tantalum were tried, with the same hydrogen and also with ordinary hydrogen, and found to give readings which were practically identical among themselves and were presumably due to stray x-rays plus the residual ionization of the electroscope. These readings were taken as the background to be subtracted from the total effect obtained with the graphite target, and the difference was ascribed to the products of a reaction involving carbon and H^2.

The ionization produced in the lead-lined chamber was about 1.4 times that produced in the paraffin-lined chamber under the same conditions, which is approximately the ratio found for γ-rays. We have also compared the absorption in paraffin with the absorption in lead and found 25 mm of paraffin to be equivalent to less than 3 mm of lead. Both of these results indicate that neutrons are not

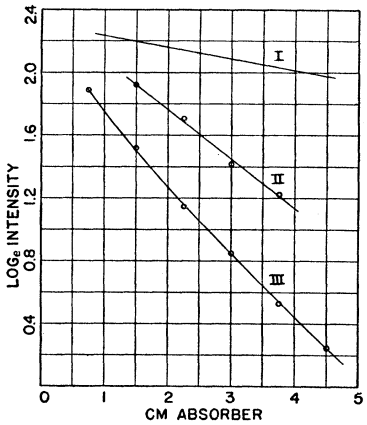

FIG. 1. Absorption in lead of I, neutrons; II, C+H^2 radiation and III, thorium γ-radiation.

present in sufficient numbers or with sufficient energy to be detected under the conditions of our experiment. We conclude therefore that the ionization is produced by very hard γ-rays.

[1] Crane, Lauritson and Soltan, Phys. Rev. **44**, 514 (1933).