THE EFFECT OF RADIOACTIVE RADIATIONS AND X-RAYS ON ENZYMES.

III. A Unit of Measure of Activity for Radium Emanation.

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(Received for publication, July 30, 1923.)

In our studies on the radiochemical reaction effected by the radiations (beta and gamma) from radium emanation in which enzymes are inactivated we have stated that in a given system the chemical change is a function of the product of two variables; namely, the average amount of emanation present, $E_o$, and time, $t$. The product of these two variables has been equated to a single variable, $W$, for which we have employed the expression “millicurie hours” as a unit of measure. This is not, however, a suitable unit of measure of the quantity of energy which $W$ represents. That no other expression has been available is due to the circumstance that up to the present time but little attention has been given to making clear a distinction between activity and amount of radium emanation. The curie is defined as the amount of emanation in equilibrium with 1 gm. of radium element. In our experiments we are concerned not only with the amount of emanation but more particularly with the activity or power of the preparation, for which no unit has yet been assigned. In this communication we shall endeavor to show the desirability of having such a unit and suggest what appears to us to be one that will meet our

1 We use activity and power synonymously in the sense in which the words are defined in physics. Cf. Duff, A. W., A text-book of physics, Philadelphia, 1916, 4th edition, 44. It is necessary that we emphasize this definition since activity is sometimes used in a descriptive sense in discussions on radioactive radiations. Thus, activity is used to denote the “intensity” of electrical, or other effect, of the radiations from one radioactive substance compared to another.
requirements. A simple means of developing a concept for this unit is suggested by the experimental fact that the activity of any given preparation of radium emanation is proportional to the amount of emanation present. Indeed, the measurement of amount of radium emanation is based on this fact.

Energy is liberated from radium emanation and its radioactive products in equilibrium with it as kinetic energy; contributed by four principal components; namely, alpha, beta, and gamma radiations and recoil atoms. The rate of liberation of this energy has been measured by Rutherford by means of converting the kinetic energy of these components into heat. From observations made in an experimental arrangement which permitted nearly complete absorption of the radiations emitted from 1 curie of radium emanation and its radioactive products in equilibrium with it, Rutherford found the rate of liberation of energy expressed in heat units, to be approximately 109.3 gram calories per hour. This rate of liberation of energy by the above mentioned source we propose to define as a unit of power or activity of such a radioactive source. As a name for this unit we suggest the expression curie-power. Accordingly the power or activity, which we shall denote as $P$, of a given preparation of radium emanation, expressed in terms of the unit curie-power, is numerically equal to the amount of emanation present, expressed in curies; i.e., the variables, $E$ and $P$, are algebraically equal. We can express the relation of the variables considered as follows:

$$E_a t = P_a t = W$$

in which $E_a$ is expressed in units of mass, curies; $P_a$ is expressed in units of activity, the curie-power; $t$ is time expressed in hours in each case. Then $W$, representing a quantity of energy, is identical with the product $P_a t$, i.e. power and time, is expressed in energy units.

\(^2\)Rutherford, E., Radioactive substances and their radiations, Cambridge, 1913, 580.

\(^3\)The unit, curie-power, will have the same significance in radium emanation measurements that the unit, candle-power, has in illumination measurements. The appropriateness of this name may be questioned but at the present time it appears to us the most fitting one we can suggest. For practical purposes the millicurie-power is used for convenience.
as it should be. Since the unit of activity is the curie-power, the energy unit will be designated the curie-power hour and 1 curie-power hour is equal to 109.3 gram calories.

We shall now consider the principles involved in the determination of the quantity of radium emanation and indicate that the determination is based on the measure of relative activity or power. For example, amounts of emanation are determined by comparing the ionizing effect of the gamma radiations emitted by a source of unknown value with the effect of the same kind of radiations emitted by a standard source containing emanation in equilibrium with a known amount of radium element. The ionization is effected in air contained in an ionization chamber and the measurements are made under fixed conditions of observation. When ionization of a gas is effected by these radiations in an electric field where the potential gradient is sufficiently great to practically prevent the recombination of ions produced, the electric current which flows is called the saturation current. The magnitude of this current depends upon the number of pairs of ions produced per unit time and its value is the measure of the ionizing effect of the radiations. It is therefore a measure of the rate of production of ions. Since the production of ions depends upon the ability of the radiations to do work it follows that the number of pairs of ions produced per unit time depends upon the amount of work done per unit time by the radiations. Clearly then, in a given system, the rate of production of ions varies with the power or activity of the radioactive source. When the value for the relative activity of two preparations is desired, as in the case of radium emanation measurements, it is necessary that the ionization be effected by radiations of the same kind or quality.

The use of the units suggested above permits us to make a more comprehensive statement of our experimental results already published. The relation which was found to exist between the chemical change observed and the variable, \( W \), is stated by the equation:

\[
\log Q - \log Q_o = - kW
\]


where the logarithms are to the base $e$; $Q_o$ is the initial concentration of active enzyme expressed in arbitrary units; $Q$ is the concentration of active enzyme found following an exposure of the enzyme solution to the radiations discussed, for a given increment of energy, $W$.\(^6\) $W$ is expressed in millicurie-power hours. From equation (1) we can write

$$W = P_o \int E dt = E_o \int e^{-\frac{E}{W}} dt$$

Now

$$E_o = \int E dt = E_o \int e^{-\frac{E}{W}} dt$$

Since

$$E = P, P_o = E_o$$

Whence

$$W = \int P dt = P_o \int e^{-\frac{E}{W}} dt = P_o e^W \tag{3}$$

In any experiment $Q_o$ is constant, therefore equation (2) may be written

$$\log Q = -kW + C$$

which on differentiation becomes

$$\frac{1}{Q} \frac{dW}{dQ} = -k, \quad \text{or} \quad \frac{dQ}{Q} = -k \frac{dW}{Q} \tag{4}$$

from equation (3) it is evident that $P dt = dW$ and if we substitute this value of $dW$ in equation (4) we can write the differential equation for the entire experiment; i.e.,

$$\frac{dQ}{Q} = -k \frac{P dt}{Q} \tag{5}$$

\(^6\) It is evident from the preceding discussion that $W$ represents the total energy liberated by the radioactive source during the period of exposure. According to Rutherford's data referred to, the energy contributed per hour per curie by the different components, expressed in gram calories, is as follows: alpha radiations and recoil atoms, 98.5; beta radiations, 4.3; and gamma radiations 6.5; total 109.3. In the arrangement employed for our experiments the alpha radiations and recoil atoms cannot penetrate the walls of the container in which the emanation is confined. Some low velocity beta radiations also fail to penetrate the walls of the container. In any experiment then we have available less than 10.8 gram calories per hour, per curie. Unfortunately, in the paper referred to in foot-note 4 these values are not correctly stated.
Hence it follows that the time rate of change in the concentration of active enzyme is proportional to the concentration of the active enzyme and the activity or power of the radium emanation.

CONCLUSION.

In this communication we have introduced a unit to express activity or power of a given preparation of radium emanation. We have named this unit the curie-power and defined it as the activity of 1 curie of radium emanation and its radioactive products in equilibrium with it. We suggest the introduction of this unit in order that we may make a more comprehensive statement of our experimental observation.

In the radiochemical reaction effected by the radiations (beta and gamma) from radium emanation in which enzymes are inactivated the chemical change in a given system is a function of the product of two variables; namely, the average activity of the radium emanation, $P_a$, expressed in terms of the unit millicurie-power, and time, $t$, expressed in hours. This product has the dimensions of energy and is identical with $W$ which is measured in terms of the energy unit, millicurie-power hours.