One further test of this relationship is possible since, on introduction of the relation $\epsilon = \frac{C}{C_{air}}$ into equation (5), it reduces to

$$\epsilon = \frac{4\pi\gamma}{\omega} - \frac{1}{2}\frac{C_0}{C_{air}}.$$

With sodium iodide in water and in methyl alcohol at 6.12 meters, the maximum power loss occurred when $\gamma_{H_2O+NaI} = 2.24 \times 10^9$ and $\gamma_{MeOH+NaI} = 1.19 \times 10^9$. Disregarding the capacity term as a second order effect and performing the indicated calculation it results that $\epsilon_{H_2O}/\epsilon_{MeOH} = 1.9$, the true ratio being 2.3. This, in view of the disturbing factors discussed above, may be considered a mildly successful corroboration.

Summary.—An expression is presented connecting power loss in a liquid dielectric with its conductivity, dielectric constant, and the frequency of the field to which it is subjected. This has been tested and verified over a considerable range of frequencies and conductivities. Its application to physiological behavior in high frequency fields is suggested.

[1] J. W. Schereschewski, *U. S. Pub. Health Repts.*, **41**, 1939 (1926); *Ibid.*, **43**, 927 (1928).

[2] R. V. Christie and A. L. Loomis, *J. Exp. Med.*, **49**, 303 (1929).

[3] Helen R. Hosmer, *Science*, **68**, 325 (1928).

[4] Kahler, Chalkley and Vaegtlin, *U. S. Pub. Health Repts.*, **44**, 339 (1929).

[5] G. W. Pierce, private communication.

[6] E. g., *Die Theorien der Radiologie*, VI, p. 647.

[7] R. W. Wood and A. L. Loomis, *Phil. Mag.*, vii, **4**, 417 (1927).

THE TEMPERATURE COEFFICIENT OF RADIOACTIVE DISINTEGRATION

BY OSCAR KNEFLER RICE[1]

GATES CHEMICAL LABORATORY, CALIFORNIA INSTITUTE OF TECHNOLOGY

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One of the most remarkable features of radioactive changes is the fact that they have extremely low-temperature coefficients, it being impossible to influence the half-life of a radioactive substance by changing the temperature over any range at our command. It is the purpose of this note to show that this is exactly what is to be expected from the known sizes of atomic nuclei, on the basis of the new quantum mechanical explanation of radioactivity.[2]

According to this explanation the alpha particle in the nucleus which is to decompose is in some "discrete" state in the nucleus, but can leak out

over a potential energy hump and appear in a continuous state outside the nucleus.[3] Now if there is to be no temperature coefficient to such a process the alpha particle must always be in its lowest discrete state when in the nucleus. If we can now calculate the probability that it should be in the next higher state at some high temperature, say 5000°, and if this probability can be shown to be negligible even at such a temperature, it will follow from the theory that a radioactive process should have no appreciable temperature coefficient. The ratio of the probability that it will be in the second quantum state to the probability that it will be in the first is given by the Boltzmann expression, $exp(-E/kT)$, where E is the difference of energy of the two states, k is Boltzmann's constant, and T the absolute temperature. We now proceed to find the order of magnitude of E.

For our purposes we may assume that the alpha particle executes harmonic vibrations within the nucleus;[4] let their frequency be ν. Then the potential energy U of the alpha particle is given in terms of ν, its mass m, and its displacement x from the position of equilibrium by the well-known equation $U = 2m\pi^2\nu^2x^2$. At the extremity of the oscillation, when all the energy is potential, U becomes just the energy of the first quantum state, which is $h\nu/2$, and accordingly we have $h\nu/2 = 2m\pi^2\nu^2x_1^2$, where x_1 is the extreme displacement for the first quantum state. We thus find $\nu = h/4\pi^2mx_1^2$. Assigning to x_1 the value 10^{-12} cm., which is of the order of the size of the nucleus (probably an upper limit for x_1) we find that ν is about 2.5×10^{19} reciprocal seconds. We multiply this by h in order to get E, and find that E is about 1.6×10^{-7} ergs. Putting this in the Boltzmann expression we find that the relative probability of an alpha particle being in the second quantum state is $exp(-2 \times 10^5)$ at 5000°C., abs. It appears impossible that the rate of escape over the potential hump should be sufficiently increased by exciting the alpha particle to the higher level to make up for the extraordinarily small probability of its being in this level.

It may be well, however, to examine the latter point in a little more detail. Since on the average an alpha particle in any level must make at least an appreciable fraction of one oscillation before decomposing, the total rate of decomposition from an excited state cannot exceed the order of magnitude of the product of the fraction of the alpha particles in that state and the frequency. This product, from the figures of the above paragraph, will be of the order of $10^{20} \times exp(-2 \times 10^5)$ per atom per second at 5000°. The actual rate of emission of alpha particles in the case of uranium, which decomposes very slowly, is about 3×10^{-18} per atom per second. This is normal decomposition, presumably from the ground level, of course; compared to the figure obtained for the first excited level, it is an enormous quantity. Furthermore, we may rest assured that the total rate of emis-

sion from all of the excited states combined is negligible, for the sum of the separate rates will converge very rapidly, due to the effect of the energy in the exponential.

Regarding the possibility of excitation to a higher rotational state, we may note that if we put the moment of inertia equal to mx_1^2 where x_1 is given the same value as before, and m is set equal to the mass of an alpha particle, the energy of the first excited rotational state will also turn out to be just 1.6×10^{-7} ergs; and even if we put m equal to the mass of the nucleus the probability of the first excited state will be extremely small, while the rate of emission will not be expected to be as effectively increased by rotational excitation as by vibrational excitation. A single level has thus been proved to be responsible for an ordinary radioactive decomposition up to temperatures of 5000° or higher, hence the process will have no appreciable coefficient over the range from 0 to 5000° or higher.

There is, however, one more point we must consider. The "discrete" levels in the nucleus are broadened out due to the fact that they are connected to a continuum outside the nucleus, so that actually an alpha particle in a given "state" within the nucleus can have a range of energies.[3] Now the probability of having a definite energy in this range will depend on the temperature, while the rate of emission will depend markedly on how near the energy is to the center of the broadened "discrete" level. But we may feel sure that the "discrete" level is really very sharp, and that we can neglect the broadening; for even in the case of RaC', which has a very short life period, the alpha particle, according to Gurney and Condon, makes on the average about (more than) e^{30} vibrations before crossing the potential energy hump.[5]

We have considered only alpha particle disintegrations, but it seems probable that similar reasoning will apply in the case of beta-particle disintegrations, especially as the mass of a beta particle is much smaller than that of an alpha particle.

[1] NATIONAL RESEARCH FELLOW.

[2] Gamow, *Zeits. Physik*, **51**, 204 (1928); Gurney and Condon, *Phys. Rev.*, **33**, 127 (1929). Later articles by various writers in *Zeitz. Physik* contain refinements to the theory. We assume it essentially complete without fine structure considerations.

[3] Gurney and Condon, loc. cit., p. 132.

[4] The exact nature of this assumption is unimportant; the really important thing is simply that the forces should be strong enough to hold the nucleus together.

[5] See figure 7 and accompanying discussion in Gurney and Condon's article.