TABLE I. Abundance of the zinc isotopes.

| Mass | 64 | 66 | 67 | 68 | 70 |
|---|---|---|---|---|---|
| Nier, 1936 | 50.9 | 27.3 | 3.9 | 17.4 | 0.5 |
| Electrolytic, I & H | 48.89 | 27.82 | 4.14 | 18.54 | 0.617 |
| Chemical, I & H | 48.90 | 27.82 | 4.17 | 18.48 | 0.623 |
| Leland and Nier, 1948 | 48.89 | 27.81 | 4.07 | 18.61 | 0.620 |

exclusively made by chemical reduction of the ore, followed by a purification by evaporation. We investigated the possibility that this earlier process might have produced the apparent enhancement of the light isotopes. This proved not to be the case; a sample of chemically reduced zinc and a sample of electrolytic zinc could not be distinguished within the accuracy of our measurements as shown in the values given in Table I, lines 2 and 3.

It should be pointed out that the 1936 values of Nier for the abundances of the zinc isotopes have been used as standards for photometric measurements by Ewald[4] and by Duckworth and Hogg[5] for the isotope abundances in copper, which gave a ratio of 2.330±0.032 and 2.277 ±0.017, respectively. These values, when corrected for the change in the zinc standards, give 2.163 for Ewald's measurements and 2.092 for Duckworth and Hogg's. Our direct electrical comparison of the copper isotopes[6] in connection with the study of meteoritic copper gave a ratio of 2.235±0.010.

* The work described in this article was performed under the auspices of the Atomic Energy Project.

[1] Report ANL-4012, p. 11, July, 1947.
[2] W. T. Leland and A. O. Nier, Phys. Rev. **73**, 1206 (1948).
[3] Alfred O. Nier, Phys. Rev. **50**, 1041 (1936).
[4] H. Ewald, Zeits. f. Physik **122**, 487 (1944).
[5] H. E. Duckworth and B. G. Hogg, Phys. Rev. **71**, 212 (1947).
[6] D. C. Hess, Jr., M. G. Inghram, and R. J. Hayden, Phys. Rev. **72**, 347 (1947).

## Space-Charge Wave Amplification Effects

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A SEARCH for better methods of generation and amplification of microwave energy has led to a conception and a successful development of an entirely new method based on space-charge wave amplification effects occurring as a result of interaction between streams of charged particles. A full account of the theory of the new method, and of the design and performance of special amplifier tubes based on the new method, will be given elsewhere.[1] It is the purpose of this letter to bring early to the attention of physicists the fact that this mechanism of interaction between particles and the associated space-charge waves plays an important part in many natural phenomena. The author believes that such effects as the abnormally intense bursts of solar radio noise associated with sun spot activity, the excess noise in electron beam tubes and magnetrons, the abnormally high temperature of electron clouds in magnetrons, and other effects will find a satisfactory explanation in terms of the new theory, the salient features of which are given below.

If a stream of charged particles of space-charge density $\rho_1$ and velocity $v_1$ is injected into the space occupied by another stream of density $\rho_2$ and velocity $v_2$, then, in addition to energy interchanges between particles in the two streams caused by scattering, there occurs a partial conversion of kinetic energy of the particles into the energy of electromagnetic fields associated with space-charge fluctuations.

If only the first-order effects of perturbation of space-charge streams are considered, and it is assumed that the density, velocity, current and voltage vary with distance $z$ and time $t$ as

$$V = V_0 \exp(\Gamma z + j\omega t),$$

where $\Gamma$ is the propagation constant and $\omega$ is the frequency of the disturbance, then by the use of the Poisson equation, the equation of conservation of charge, and the force equation, the following expression for $\Gamma$ can readily be derived in terms of velocities $v_i$ of the $i$ components of the stream and the corresponding plasma frequencies $\omega_i = \left(\frac{e}{m}\cdot\frac{\rho_i}{\epsilon}\right)^{\frac{1}{2}}$.

$$\sum_1^i \frac{\omega_i^2}{(\omega + j\Gamma v_i)^2} = 1. \qquad (1)$$

For a stream consisting of only two components of velocities $v_1$ and $v_2$, the real component of $\Gamma$, for a special case $\omega_1 = \omega_2$ is given by:

$$\Gamma_{\text{real}} = \pm j\frac{\omega_1}{v}\left(\left(\frac{\delta\omega}{v\omega_1}\right)^2 + 1 - \left(4\left(\frac{\delta\omega}{v\omega_1}\right)^2 + 1\right)^{\frac{1}{2}}\right)^{\frac{1}{2}}. \qquad (2)$$

where $\delta = \frac{1}{2}(v_1 - v_2)$ and $v = \frac{1}{2}(v_1 + v_2)$.

Amplification of space-charge waves occurs only over a limited range of the factor $(\delta\omega/v\omega_1)$ which has been named the inhomogeneity factor. The initial amplitude of the disturbance $(V_0)$ increases exponentially as the space-charge waves travel with the particles in the stream so that the gain in energy of the original disturbance after it traveled a distance $z$ is given by $e^{2\Gamma z}$. Even with moderate charge densities very high energy gain per unit length of the particle stream can be realized. Experimental tubes based on this principle and called the "electron wave tubes" have produced at a frequency of 3000 megacycles electronic gains as high as 80 decibels with electron streams only 20 cm in length and average currents of a few milliamperes. At the same time, the frequency range over which effective amplification takes place is very wide and is approximately given by

$$\Delta\omega \approx \omega\frac{2.32}{(\text{Gain})^{\frac{1}{2}}}. \qquad (3)$$

The frequency $\omega_m$ corresponding to maximum gain is given by $\omega_m = (\sqrt{3}/2)\cdot(v/\delta)\cdot\omega_1$ and can be much higher than the plasma frequency $\omega_1$.

It is a most striking feature of the new mechanism of energy amplification that it occurs entirely because of interaction of the different components of the stream through their space-charge fields without the presence of any field-supporting resonant or wave-guiding structures. Because of this feature, the electron wave tube offers a very promising solution to the problem of generation and amplification of energy at millimeter wave-lengths. This feature also makes it easy to understand how electromagnetic radiation over limited frequency bands is produced in nature whenever there exist inhomogeneous streams of charged particles. For example, streams of charged corpuscles emerging from sun spots during solar flares present just such conditions where enormous amplification of space charge fluctuations can occur over a limited frequency range determined by the composition of the streams. The associated space-charge fields radiate the electromagnetic energy in this frequency band, and it is usually observed in radio telescopes as intense bursts of solar noise. Application[2] of the above theory made it possible to estimate the expected spectral energy distribution of radio noise associated with solar flares which agrees well with measurements such as those of Appleton and Hey.[3]

The excess noise in electron-beam tubes and in magnetrons can also be explained in terms of the new theory. The inhomogeneity of the electron stream in beam tubes is caused by d.c. space-charge field and the excess noise is then the result of amplification of the original shot noise due to interaction of the different velocity components of the stream. In magnetrons the original fluctuations of cathode current create fluctuations of space-charge field. These fluctuating fields or waves interact with electrons in such a manner that original fluctuations increase in amplitude and some electrons gain and some lose energy. Since at cut-off fields many electrons return to the cathode, the space-charge waves also travel in both directions and the amplification proceeds to a saturation level determined by the anode potential, the magnetic field, and the density of the electron cloud. Some electrons can thus attain high excess energy proportional to anode potential so that the final energy distribution of the electron cloud may correspond to an apparent temperature of millions of degrees.[4] The flow of current to the anode at magnetic fields exceeding cut-off value can thus be understood.

[1] The author's paper on "The electron wave tube—A novel method of generation and amplification of microwave energy" has been submitted to the Proc. I. R. E.

[2] A fuller account of the theory of generation of abnormal solar radio noise is the subject of a paper now in preparation.

[3] E. Appleton and J. S. Hey, "Solar radio noise," Phil. Mag. **37**, 73–84 (1946).

[4] E. G. Linder, "Excess-energy electrons and electron motion in high-vacuum tubes," Proc. I.R.E. **26**, 346–71 (1938).

## Disintegration of Deuterium by Gamma-Rays from $^{24}$Na

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According to theory, the angular distribution of protons created by the process ${}^2{}_1D+h\nu\rightarrow{}^1{}_1H+{}^1{}_0n$ can be described by the formula $n_\theta=a+b\sin^2\theta$, where $n_\theta$ is the number of protons emitted per unit solid angle in a direction making an angle $\theta$ with the direction of the incident $\gamma$-rays, and $a$ and $b$ are constants. The first constant term is caused by the so-called photomagnetic effect, the second term to the photoelectric effect. The ratio $\sigma_m/\sigma_e$ between the cross sections for the two processes can be derived when the ratio $n_{0°}/n_{90°}=a/(a+b)$ is measured, and such measurements have been performed by several investigators.[1–5] However, since the various results do not agree with each other and, furthermore, since mainly the angles $\theta=0°$ and $\theta=90°$ have been examined, measurements of the angular distribution were undertaken by means of a new method.

The instrument used was a battery of proportional counters arranged in parallel and filled with pure deuterium. Each counter was cylindrical, having a length ten times the diameter. The photo-protons created in the gas inside the tubes were recorded by means of a proportional amplifier and a cathode-ray oscillograph which was photographed on a moving film. The magnitude of the pressure inside the counters was such that the range of the protons was about $\frac{3}{4}$ the counter diameter. Hence, protons traveling perpendicularly to the axis of the counters will hit the walls and only a small part of their tracks will lie inside the counters; consequently, these protons will give rise to much smaller pulses on the oscillograph than those moving parallel to the counter axis. Only protons moving in directions deviating from the axis by less than a certain small angle, the magnitude of which is determined by the range and the counter diameter, will end their paths inside the counters and produce pulses of maximum size. A simple calculation shows that the pulse-size distribution curve falls off with increasing pulse sizes, except in the very end where a peak occurs, the height of which is determined by the accuracy of the pulse-size measurements. In order to get reasonably good statistics it was necessary to use a rather strong $\gamma$-irradiation (~500 millicuries at a distance of 30 cm), which caused a high background ionization in the counters and consequently a background noise on the oscillograph, which involved a rather high spread in the pulse size measurements. Nevertheless, a pulse size distribution curve with a peak was actually obtained, as shown in Fig. 1. The protons corresponding to this peak will have tracks deviating but little from the counter axis, and hence the angular distribution of the protons can be obtained by measuring the number corresponding to the peak for varying values of the angle $\theta$ between the $\gamma$-rays and the counter axis. For small values of $\theta$ two peaks corresponding

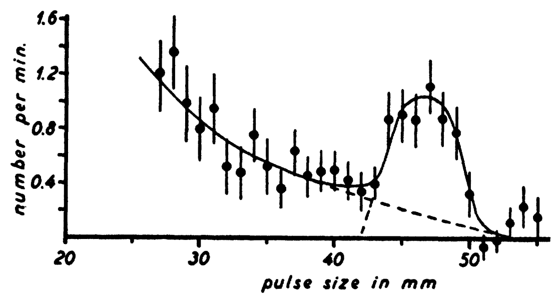


FIG. 1. Pulse-size distribution curve obtained for $\theta=90°$.