On July 7th the equipment was carefully checked and no defects could be found. This together with the slow build-up of the anomaly makes it quite assuring that the observed effect is connected with the release of radioactive substances during the bomb test. (Air temperature, barometric pressure, and wind velocities were normal during the anomaly.)

The maximum observed increase in gamma-ray intensity is 77 percent. The half-width of the anomaly is 5 hours. The maximum occurs 108 hours after the bomb explosion. This corresponds to a travelling speed of the radioactive material in excess of 60 miles per hour.

Volt-Ampere Characteristics for the Flow of Ions or Electrons Between Concentric Cylinders in Gases at Atmospheric Pressure

CHESTER W. RICE
General Electric Company, Schenectady, New York
July 18, 1946

THE following equations give the volt-ampere characteristics for the flow of current from a cylindrical emitter of radius r_1 to a surrounding coaxial collector of radius r_2, before ionization by collision begins. The emitter may be either a positive ion or electron source. The mean free path in the gas between the electrodes is assumed to be small compared with the electrode spacing.

The similar case for parallel planes was treated by J. J. Thomson[1] and we here apply his method to the case of concentric cylinders.

Poissons' equation in cylindrical coordinates may be written

$$\frac{1}{r}\frac{d}{dr}(Xr)=4\pi\rho, \tag{1}$$

where r equals the radius, X equals the potential gradient dV/dr, and ρ is the space-charge density.

The second equation that we assume is

$$i=2\pi r\rho\mu X, \tag{2}$$

where i is the current per unit length of cylinder and μ is the positive ion or electron mobility (i.e., velocity for unit potential gradient) all in c.g.s. electrostatic units.

We first substitute the value of ρ from (2) in (1), then separate the variables and integrate to obtain

$$X=\pm\left(\frac{2i}{\mu}+\frac{C}{r^2}\right)^{\frac{1}{2}}, \tag{3}$$

where C is the constant of integration. We determine C as follows. We have

$$\rho=ne, \tag{4}$$

where n equals the number of ions or electrons per unit volume and e the charge per ion or electron. If we substitute this value of ρ and the value of X from (3) in (2) we obtain

$$n=\frac{i}{2\pi re\mu(2i/\mu+C/r^2)^{\frac{1}{2}}}. \tag{5}$$

If we let n_1 equal the value of n at the surface of the emitter r_1, we have from (5)

$$n_1=\frac{i}{2\pi r_1 e\mu(2i/\mu+C/r_1^2)^{\frac{1}{2}}}. \tag{6}$$

A second equation from n_1 which we will derive below is

$$n_1=\frac{(6\pi)^{\frac{1}{2}}(I-i)}{2\pi r_1 ce}, \tag{7}$$

where I is the saturation current per unit length of emitter and c is the r.m.s. velocity of the ion or electron at the emitter temperature.

Equating (6) and (7) and solving for C, we obtain

$$C=\frac{r_1^2c^2}{6\pi\mu^2}\left(\frac{i}{I-i}\right)^2-\frac{2ir_1^2}{\mu}. \tag{8}$$

To save space, we write

$$a^2=\frac{c^2}{6\pi\mu^2}\left(\frac{i}{I-i}\right)^2, \tag{9}$$

and

$$b=2i/\mu. \tag{10}$$

Hence,

$$C=r_1^2a^2-r_1^2b. \tag{11}$$

If we substitute (11) back in (3), we obtain the general solution for the potential gradient

$$X=\frac{b^{\frac{1}{2}}(r^2+[r_1^2a^2-r_1^2b]/b)^{\frac{1}{2}}}{r}. \tag{12}$$

Before integrating this expression to obtain the volt-ampere characteristics, we will go back and derive Eq. (7). Here we assume that the net current i leaving the emitter is equal to the saturation current I of the emitter minus the back diffusion current i_b, that is

$$i=I-i_b. \tag{A}$$

From the kinetic theory of gases we have

$$i_b=2\pi r_1 n_1 ce/(6\pi)^{\frac{1}{2}}, \tag{B}$$

where the r.m.s. velocity c equals $(3kT/m)^{\frac{1}{2}}$, k equals 1.37×10^{-16} Boltzmann's constant, T the absolute temperature of the emitter, and m the mass of the ion or electron.

Substituting (B) in (A) and solving for n_1 we obtain the desired Eq. (7).

We now integrate Eq. (12) and obtain solutions which are suitable for calculating the volt-ampere characteristic for different conditions. No single solution appears to be suitable to cover the whole volt-ampere characteristic under all conditions.

In general,

$$V|_1{}^2=\int_{r_1}^{r_2}Xdr=b^{\frac{1}{2}}\int_{r_1}^{r_2}\frac{[r^2+(r_1^2a^2-r_1^2b)/b]^{\frac{1}{2}}}{r}dr. \tag{13}$$

Peirce[2] Eq. (130) gives for the full equation

$$V|_1{}^2=[r_1^2a^2+b(r_2^2-r_1^2)]^{\frac{1}{2}}-r_1a+[r_1^2a^2-r_1^2b]^{\frac{1}{2}} \times\log_e\frac{r_2}{r_1}\frac{[r_1^2a^2-r_1^2b]^{\frac{1}{2}}+r_1a}{[r_1^2a^2-r_1^2b]^{\frac{1}{2}}+[r_1^2a^2+b(r_2^2-r_1^2)]^{\frac{1}{2}}}. \tag{14}$$

The above equation is only good when $r_1^2a^2$ is greater than r_1^2b.

Case A. When $r_1^2a^2$ is small compared with br_1^2 we have the full space-charge condition and (13) reduces to

$$V|_1^2=b^{\frac{1}{2}}\int_{r_1}^{r_2}\frac{(r^2-r_1^2)^{\frac{1}{2}}}{r}dr. \tag{15}$$

Peirce[2] Eq. (131) gives

$$V|_1^2=b^{\frac{1}{2}}([r_2^2-r_1^2]^{\frac{1}{2}}-r_1\cos^{-1}[r_1/r_2]). \tag{16}$$

Case B. When $r_1^2a^2$ is large compared with br_1^2 we have a transition equation from the full space-charge condition to no space charge. Here (13) reduces to

$$V|_1^2=b^{\frac{1}{2}}\int_{r_1}^{r_2}\frac{(r^2+r_1^2a/b)^{\frac{1}{2}}}{r}dr. \tag{17}$$

Peirce[2] Eq. (130) gives

$$V|_1^2=(r_1^2a^2+br_2^2)^{\frac{1}{2}}-(r_1^2a^2+br_1^2)^{\frac{1}{2}}+r_1a\log_\epsilon\frac{r_2}{r_1}\frac{r_1a+(r_1^2a^2+br_1^2)^{\frac{1}{2}}}{r_1a+(r_1^2a^2+br_2^2)^{\frac{1}{2}}}. \tag{18}$$

Case C. When $r_1^2a^2$ is large compared with both br_1^2 and br_2^2. In this case the current is limited by back diffusion only and Eq. (18) reduces to

$$V|_1^2=r_1a\log_\epsilon r_2/r_1. \tag{19}$$

As previously stated, the above equations are all in c.g.s. electrostatic units. For calculation we will want to use cm, gram, second, volts, amperes per cm, length, and mobility in cm/sec./volt/cm. In that case a remains

$$a=\frac{c}{(6\pi)^{\frac{1}{2}}\mu}\left(\frac{i}{I-i}\right), \tag{20}$$

and b becomes

$$b=0.903\times10^{12}\,2i/\mu. \tag{21}$$

It was interesting to find experimentally that these equations which are based on a constant mobility gave a good fit to the experimental volt-ampere characteristics, under a wide variety of conditions, for both electron and lithium positive ion emitters in air at atmospheric pressure.

[1] J. J. Thomson, *Conduction of Electricity through Gases* (The Cambridge University Press, New York), second edition, p. 267.
[2] B. O. Peirce, *A Short Table of Integrals* (Ginn and Company, New York).

Note on Thickness of Quartz Wafers for Observed Surface Phenomena

D. D'Eustachio
Bliley Manufacturing Corporation, Erie, Pennsylvania
July 16, 1946

THE writer and his co-workers have reported some effects occurring on thin crystals.[1–3] In this work the critical thickness has been given as 25–30 microns. These figures for thickness do not take into account the depth of the etch pits developed on the surface. Examination of the cross sections of some of the plates, and more recent work with smoother surfaces indicate that the thickness is ~10 microns.

[1] D. D'Eustachio and S. B. Brody, Phys. Rev. **69**, 256 (1946).
[2] D. D'Eustachio, Paper presented at the Cambridge Meeting of the Am. Phys. Soc., April, 1946.
[3] D. D'Eustachio and S. Greenwald, Phys. Rev. **69**, 532 (1946).

Spontaneous Emission of Neutrons from Uranium*

G. Scharff-Goldhaber and G. S. Klaiber
Department of Physics, University of Illinois, Urbana, Illinois
May 18, 1942

FLEROV and Petrzhak[1] have established the existence of spontaneous fission in uranium by recording the heavy fission fragments with a uranium-coated ionization chamber. The partial decay constant of the "average uranium atom" calculated from their data lies between 2×10^{-25} and 2×10^{-24} sec.$^{-1}$ for this process. It seemed possible that the mechanism of spontaneous fission might be different from that of induced fission, in particular that no neutrons might be split off in the former process. Libby[2] had previously made an unsuccessful attempt to find spontaneous fission neutrons with the help of a boron counter. His results indicated an upper limit for the partial disintegration constant of 2×10^{-22} sec.$^{-1}$ for spontaneous fission with neutron emission. We have now carried out an experiment with a more sensitive calibrated arrangement, using a hydrogen-filled ionization chamber which allowed us to record neutrons of an energy higher than about 100 kev.[3] Spontaneous emission of neutrons from uranium was observed. Several sources of error were excluded by check experiments and simple considerations. From the number of counts obtained we estimate the partial decay constant for spontaneous fission for the "average uranium atom" to be of the order of 7×10^{-24} sec.$^{-1}$ under the assumption that one neutron is emitted per fission. Neutrons with energies up to 800 kev have been observed.

* This paper was received for publication on the date indicated, but was voluntarily withheld from publication until the end of the war.
[1] G. N. Flerov and K. A. Petrzhak, J. Phys. U.S.S.R. **3**, 275 (1940).
[2] W. F. Libby, Phys. Rev. **55**, 1269 (1939).
[3] G. S. Klaiber and G. Scharff-Goldhaber, Phys. Rev. **61**, 733 (A) (1942).

On the Production of Penetrating Ionizing Particles by the Non-Ionizing Component of Cosmic Radiation

P. J. G. de Vos
Merensky Instituut vir Fisika, Universiteit van Stellenbosch, Stellenbosch, South Africa
and
S. J. du Toit
Departement vir Natuurkunde, Universiteitskollege vir C. H. O., Potchefstroom, South Africa
Jnly 22, 1946

EXPERIMENTS of the type using a vertical coincidence set of two or more counter tubes, in which an absorber is placed either above the whole system, or between the two top counters, have been reported by various authors.[1–6] All these experiments are in agreement in that they give an increased coincidence rate with the absorber in the first position as compared to that with the absorber in between the counters.

In all these experiments, except those of Froman and Stearns,[5] the material shifted during the experiment was either iron or lead, and the increase in counting rate was found to be relatively small. Rossi *et al.*,[7] using the anti-coincidence method, have shown conclusively that the