Boltzmann populations for the 6^3D states of Hg, as assumed by these authors for their Hg doped carbon arc.

Details will be published elsewhere.

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The Gamma-Rays from $Be^9(\alpha, n)$

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April 17, 1950

WE have recently applied a scintillation gamma-ray spectrometer[1] to the study of high energy gamma-rays which give rise to electron pairs in the scintillation element of NaI (Tl), as a result of their interaction with the I atoms in the crystal lattice. The total kinetic energy of the pairs ($E_\gamma - 1.02$ Mev) appears as the energy of pair production lines when the differential pulse-height distribution of the crystal scintillations is examined in an arrangement similar to the one which we have been using in the lower energy region.[1] Used in this manner the device might be termed a scintillation pair spectrometer.

A satisfactory resolution has been achieved as a direct consequence of the high energies involved and of certain improvements to the original equipment, and we wish to report some interesting results which have been obtained with the very weak gamma-rays produced in the bombardment of beryllium with polonium alpha-particles. These gamma-rays are attributed to the de-excitation of the excited levels of the residual C^{12} nucleus which is formed in the reaction. Previous measurements of these gamma-ray energies[2] have yielded somewhat confusing results, but much work has been done on the level scheme involved by a study of the neutron groups which are produced.[2] It was therefore thought to be of interest to investigate the gamma-rays with the scintillation pair spectrometer, which is ideally suited to a study of very weak sources.

The ThC'' gamma-ray of 2.62 Mev was used for the purpose of calibration (Fig. 1), and a small pair production peak, A, due to this gamma-ray can be identified at 1.60 Mev on the pulse-height scale. This is superimposed on a well-defined Compton distribution, B. As the pair production cross section is relatively low for this gamma-ray energy, an accurately known gamma-ray of somewhat higher energy, if available, would be better suited for calibration purposes. The source used was about 10 grams of thorium nitrate, which illustrates the extreme sensitivity of the device. The Po-Be source strength was not known accurately but was believed to give approximately 5×10^3 neutrons/sec. The direct effect of these neutrons on the crystal was shown to be small and the pulse-height distribution curve obtained with this source is substantially due to gamma-rays alone. The predominant feature of the C^{12} curve is the pair production peak, C, corresponding to a gamma-ray energy of 4.40 ± 0.05 Mev superimposed on a sharp Compton distribution, D. The resolution of this line, defined in terms of its full width at half-height, appears to be about eight percent. This sharply resolved peak gives us confidence that the linear relation[1] between pulse height and energy extends to this region, as otherwise a broad distribution would be obtained as a result of the nature of the pair production process. No significant gamma-ray of energy in the range 2 to 4 Mev is found. However, there is evidence for the existence of a very weak gamma-ray at approximately 7.2 Mev. A detailed study of this region was difficult because of the weakness of the available source, and the low relative intensity of the gamma-ray which has been estimated as about one percent of the lower energy component.

The existence of an excited level of C^{12} at 4.40 ± 0.05 Mev and the absence of other levels except the weak high energy 7.2-Mev level is in complete agreement with results which have been obtained recently by Bradford and Bennett[3] from a study of the neutron groups involved.

A considerable amount of work has been done on the study of the photo-electron lines produced by low energy gamma-rays in the scintillation spectrometer and a report of this work will be published shortly. The National Research Council of Canada has given us support in this project.

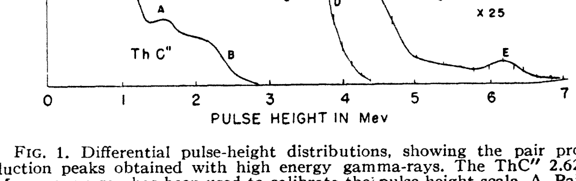

FIG. 1. Differential pulse-height distributions, showing the pair production peaks obtained with high energy gamma-rays. The ThC'' 2.62-Mev gamma-ray has been used to calibrate the pulse-height scale. A. Pair production due to ThC'' 2.62-Mev gamma-ray. B. Compton edge due to ThC'' 2.62-Mev gamma-ray. C. Pair production due to C^{12} gamma-ray (4.40 Mev). D. Compton edge due to C^{12} gamma-ray (4.40 Mev). E. Pair production due to weak C^{12} gamma-ray (7.2 Mev).

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Can the Rectifier Become a Thermodynamical Demon?

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April 17, 1950

A RESISTOR R, maintained at the absolute temperature T, is a source of random electromotive forces e_ν

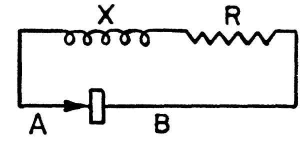
$$\langle e_\nu^2\rangle_{\mathrm{Av}} = 4RkTd\nu \qquad (1)$$

for a small frequency interval $d\nu$. This is the well-known Nyquist formula. Let us connect the resistor in series with a rectifier. It seems as if the rectifier should rectify these random oscillations and produce a direct voltage. With a large number of such circuits in series one might obtain a voltage high enough to charge a battery. This means a possibility of doing work with just one source of heat at one temperature, in obvious contradiction with the second principle of thermodynamics.

Let us investigate how this problem can be solved. We consider the circuit of Fig. 1 with an impedance, at frequency ν,

$$Z = R + jX \qquad (2)$$

FIG. 1. Circuit with rectifier.



in series with a rectifier, for which we assume a relation

$$V_A - V_B = f = ri + bi^2 \tag{3}$$

between the difference of potential f and the current i.

At a temperature T, electromotive forces φ will be generated in the circuit, for the frequency band $d\nu$, and may contribute to the d.c. electromotive force. We assume

$$\varphi = \varphi_0 + \varphi_\nu$$
$$\langle\varphi\rangle_{\text{Av}} = \varphi_0 \quad \langle\varphi_\nu\rangle_{\text{Av}} = 0 \quad \langle\varphi_\nu{}^2\rangle_{\text{Av}} = 0, \tag{4}$$

thus splitting the d.c. component of φ_0 from the oscillating term φ_ν.

These electromotive forces produce a current i with a d.c. component i_0 and an oscillating component i_ν

$$\varphi_\nu = (R + r + jX)i_\nu \tag{5}$$

and

$$\langle\varphi\rangle_{\text{Av}} = \varphi_0 = (R+r)i_0 + b\langle i_\nu{}^2\rangle_{\text{Av}} \tag{6}$$

assuming $X = 0$ for direct currents.

The second principle of thermodynamics requires that i_0 be zero on the average, in order to give no average potential difference, $V_A - V_B$, so that

$$\langle i_0\rangle_{\text{Av}} = 0$$

and Eq. (5) yields, after averaging,

$$\langle\varphi\rangle_{\text{Av}} = \varphi_0 = b\langle i^2\rangle_{\text{Av}}. \tag{7}$$

This means that the d.c. component of the fluctuation exactly cancels the rectified voltage due to the thermal oscillating current. Furthermore, the Nyquist formula (1) must apply to the r term of the rectifier [Eq. (3)] as well as to the resistor R. Suppose for a moment that the thermal noise in the rectifier is stronger than in a resistance of similar r-value. This would mean that the noise from the rectifier should heat up the resistor R and produce, after a while, a difference in temperature between rectifier and resistor; this would again be a contradiction of the second principle. This proves that

$$\langle\varphi_\nu{}^2\rangle_{\text{Av}} = 4(R+r)kTd\nu, \tag{8}$$

a formula similar to (1), applied to the whole circuit. Hence

$$\langle i_\nu{}^2\rangle_{\text{Av}} = \frac{\langle\varphi_\nu{}^2\rangle_{\text{Av}}}{(R+r)^2 + X^2} = 4\frac{R+r}{(R+r)^2+X^2}kTd\nu \tag{9}$$

and finally with the help of Eqs. (7) and (9)

$$\varphi_0 = b\langle i_\nu{}^2\rangle_{\text{Av}} = 4b\frac{R+r}{(R+r)^2+X^2}kTd\nu. \tag{10}$$

The direct component of the noise, corresponding to the frequency band $d\nu$, depends on the properties R, X of the whole circuit. There is no rectified current in the circuit, and no direct voltage across the rectifier. For an actual electric circuit, X depends on ν, and an integration performed on Eq. (10), from $\nu = 0$ to $\nu = \infty$ yields the total direct φ_0-term. Application of the formula to special examples always shows a complete compensation of direct average voltage.

The whole procedure is an example of the general method of detailed balancing discussed by Bridgman.[1]

[1] P. W. Bridgman, Phys. Rev. 31, 101 (1928).

Nuclear Recoil Momentum in Pair Production

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April 17, 1950

RECENTLY[1] Modesitt and Koch investigated the production of electron pairs by γ-ray quanta in an air filled cloud chamber. They made measurements of the momentum transferred to nuclei in the creation of pairs by quanta of energies ranging from 1.02 to 19.5 Mev. The momentum imparted to the nucleus is related to the distance from the nucleus at which the electron pairs are formed. The data on recoil momenta of nuclei then constitute a test of a feature of the theory of pair production.

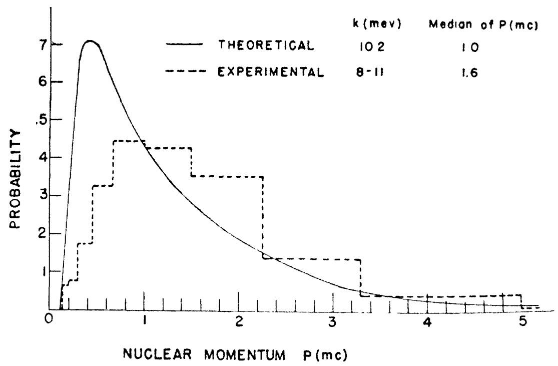

FIG. 1. The theoretical and experimental probability distribution curve of nuclear recoil momentum for pair production in air.

Bethe and Heitler[2] have given the theory of pair production by a γ-ray quantum in the Coulomb field of a nucleus. For large enough quantum energy the theory predicts a simple probability distribution for the nuclear recoil momentum[3]

$$\phi(p)dp = \text{const.}dp/p,$$

provided

$$1 \gg p/mc \gg \delta/mc = mc^2k/2E_+E_-.$$

Here δ is the minimum possible momentum transfer. However, the quantum energies used in the experiments[1] are too small to justify comparison with the simple formula above, since the minimum value of δ/mc (at say $k = 20\ mc^2$) is 0.1, which hardly allows p to satisfy the conditions.

In order to obtain a formula which can justly be compared with experiment an exact numerical calculation of $\phi(p)$ was made for a quantum energy typical for the experiments, $k = 20$ cm^2. Bethe[3] has given, by simple alterations of his Eq. (32), a form of the differential cross section for pair production which is convenient for integration. Part of the necessary integrations in calculating $\phi(p)$ were performed analytically by Bethe. Further work then consisted essentially of numerical integration.

The theoretical probability curve at $k = 10.2$ Mev and the experimental results for the range 8 to 11 Mev are shown in Fig. 1. The calculated median momentum 1.0 mc and the experimental 1.6 mc are in disagreement. The validity of the Born approximation is hardly in doubt since the pair production took place in air; furthermore, screening is negligible in the range of recoil momenta involved. It is clear from the figure that the simple dp/p law at this energy is a poor approximation to the actual theoretical curve.

At higher quantum energies the theoretical distribution function approaches the simple asymptotic formula given by Bethe. The concentration of momentum transfers in the neighborhood of the minimum momentum increases with increasing quantum energy and the median, consequently, decreases. In the data of Modesitt and Koch there is no such variation of the median momentum with quantum energy. The form of their histograms is essentially the same from 3 to 19.5 Mev. Their set of observed median momenta are larger than predicted by the theory, the difference being greatest for highest energy range, 17.0 to 19.5 Mev. This disagreement between theoretical predictions and experiment has not been explained.

The author wishes to express his gratitude to Professor A. Nordsieck for suggesting this problem and for his interesting and helpful discussions.

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