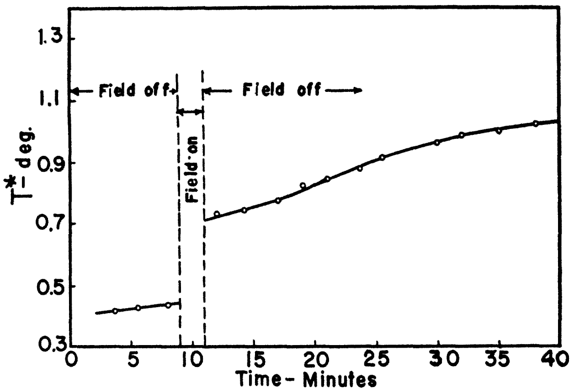

FIG. 1. Sample warm-up curve for a 3 cc chromium potassium alum ellipsoid.

of warm-up of the ellipsoids. Temperatures were calculated from ballistic mutual inductance measurements of the susceptibilities of the ellipsoids as described in previous publications.[2]

The thermal conductivity of both Sn and Ta was found to be considerably smaller in the superconducting state than in the normal state; for example for Ta the ratio of these conductivities, K_s/K_n, was found to be somewhat less than 1/60 at 0.55°K, and for Sn, $K_s/K_n \simeq 1/40$ at 0.65°K. It appeared that below 1°K the thermal conductivity of two different samples of Sn of the same purity could be expressed by $K_s = cT^3$ with $c = 1.1\times 10^{-2}$ watt-unit. The results both for Sn and Ta were approximately such as would be expected if $K_s/K_n = (T/T_c)^2$, a relationship that can be deduced if at these low temperatures the thermal resistance is largely due to impurity scattering. Our measured values of K_s/K_n below 0.6°K were higher than those given theoretically by Heisenberg.[3]

By extrapolation our results to lower temperatures (<0.1°K) it would appear the ratio K_s/K_n would become very small, e.g., for Sn at 0.01°K, $K_s/K_n \simeq 7\times 10^{-6}$, effectively describing the superconducting state as a thermal insulator.[4] Heat contact could therefore be made or broken, as process necessary for example for a two stage magnetic cooling system,[1] by having a metallic link either in the normal or superconducting state, a change that can easily be affected by the application of small external magnetic fields.

In experiments with magnetic cooling systems, it has been found sufficient to connect thermally the paramagnetic salt with the helium bath by a fine wire of superconducting material having a high transition temperature and dispense with the usual exchange gas. During magnetization at 1°K the wire is in the normal state and effectively conducts to the bath the heat of magnetization. On demagnetization the metallic link between the paramagnetic salt and the helium bath becomes superconductive and forms a satisfactory insulating support. Such a technique not only has the advantage of dispensing with exchange gas and its attendant equipment, but also the long periods of magnetization, which are generally required in order to pump out exchange gas, are considerably reduced. As an example of the effectiveness of this procedure we give in Fig. 1 a warm-up curve for a 3 cc chromium potassium alum ellipsoid thermally connected to a helium bath at 1.13°K through 56 cm of 0.017-cm diameter tantalum wire. From minute 0 to minute 9, the wire was in the superconducting state and the heat influx to the ellipsoid was approximately 7.3 ergs/sec. From minute 9 to minute 11 the Ta wire was transformed into the normal state by the application of a transverse field of 600 gauss. As a result the temperature of the ellipsoid rose immediately to 0.71°K, corresponding to a heat gain of 1.5×10^4 ergs. At minute 11 the wire being again in the superconducting state the heat influx to the ellipsoid fell back again to 6.7 ergs/sec.

The new technique outlined here would become still more effective if heat barriers composed of additional salt systems were employed[5] and experiments are now being carried out on this extension of the technique.

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[1] Simon, Reports of Conference on Magnetism at Strasbourg, 1939 (Institut International de Cooperation Intellectuelle, 1940), Vol. III, p. 1.

[2] For further detail see J. G. Daunt and C. V. Heer, Phys. Rev. **76**, 715 (1949).

[3] W. Heisenberg, Zeits. f. Naturforschung **3a**, 65 (1948).

[4] A discussion of these possibilities has been made also by Casimir, Oak Ridge Conference on Nuclear Physics and Low Temperatures, August 7, 1948.

[5] Cooke and Hull, Proc. Roy. Soc. **181**, 83 (1942).

Ion Source for Mass Spectrography

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August 1, 1949

It is known that the cathode material of a canal-ray tube sputters during the discharge. In this case neutral molecules or negative ions only can leave the cathode because positive ions are strongly linked to the cathode by the electric field. Those few neutral molecules only, which are ionized by accident on the axis of the discharge tube, especially near the anode, may leave the tube in form of canal-rays, if they are not scattered by gas molecules. Though the number of these particles may be very small and therefore the intensity low, this process has been successfully tried in many investigations in mass spectrography.

We have improved this method very materially:

(1) There are two electric fields: First the electric field in the canal-ray tube (A), (see Fig. 1) which is completely separated from the electric field immediately in front of the trial-substance (C). The first one produces the beam (B) of canal-rays, which causes the sputtering. The second one has the right direction to remove and accelerate the positive ions of the trial-substance for analysis in a mass spectrograph. It is produced by the cylinders (D) and (E), which are at different voltages.

(2) The sputtering takes place in a high vacuum, because the gas-filled canal-ray tube (A) is separated by the narrow canal (K) (which has a large gas-current resistance) from the space in front of the substance. This space is connected with a pump of high pumping speed. Hereby, losses by scattering on gas molecules can be avoided almost completely.

(3) All ions will be produced on an electric equipotential-surface and will be accelerated by the same voltage. Therefore the ions get a uniform energy. Hence of producing a mass spectrogram a magnetic field alone is sufficient, which is a great advantage. But it is an advantage too for mass spectrographs with energy-focusing,

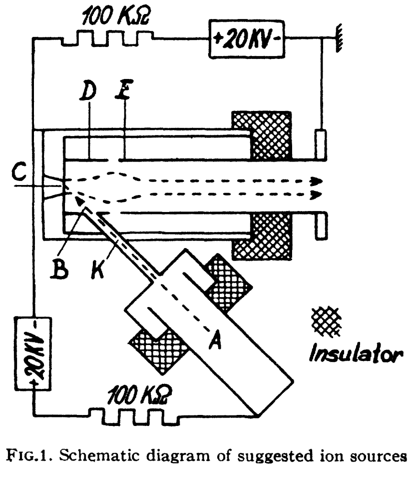

FIG. 1. Schematic diagram of suggested ion sources.

if the ions have already a nearly uniform energy, because the losses may be avoided, which always otherwise arise, if the rays hit the screen, which limits the small interval of energy.

(4) The electric field between the cylinders (*D*) and (*E*), which accelerates the positive ions of the substance, will be formed so that it works as an electron-optic lens and produces a nearly parallel beam of rays.

We have tried out such an arrangement, and found it to work most satisfactorily. The intensity is dependent on the trial-substance and was large for metals and smaller for salts. The analysis in the parabola-spectrograph shows the ions of the trial-substance and the ions of the primary canal-ray discharge, all having the same energy.

On the Spin of μ-Mesons

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August 8, 1949

THE known processes resulting from the interaction of μ-mesons with other elementary particles:

$$\pi\rightarrow\mu+\mu_0, \tag{1}$$

$$\mu\rightarrow\mu_0+e+\nu, \tag{2}$$

$$P+\mu^-\rightarrow N+\mu_0 \tag{3}$$

give very little indication on the spin of μ-mesons. We can only say that μ and μ_0 have both integral or half-integral spin.

As in all these processes μ appears together with μ_0 we shall assume that they are two different states of charge of the same particle and thus that they have the same spin.

The possibility of a spin $\frac{1}{2}$ for these particles has been already considered[1] (in particular if μ_0 is a neutrino). Although the hypothesis of μ_0 being a neutrino is very appealing, it seems that one should not neglect the other possibilities, in particular that it has an integer spin. From the analysis of the frequency of bursts produced by cosmic-ray mesons at sea level (mostly μ-mesons), Christy and Kusaka[2] excluded the value 1 for the spin of these mesons. If we exclude values higher than 1 (which may eventually result from an extension of Christy-Kusaka's calculations) we are left only with the values 0 and $\frac{1}{2}$.

We want to show here that a zero spin for the μ-meson with a special type of coupling with electron, neutrino and nucleons is in good agreement with the experimental results.

Let us consider first the μ-decay. We describe μ and μ_0 mesons by scalar (or pseudoscalar) fields, respectively complex (Φ) and real (φ). In order that μ-decay be a first-order process we take the interaction Lagrangean bilinear[3] in the mesonic fields; the most general one that can be formed using at most first derivatives[4] of the mesonic fields *and* of the electron-neutrino wave functions (ψ)[5] is:

$$L_{\text{int}}=\psi^+\left\{\left[g_1\Phi\varphi+\frac{g_2}{\kappa}\varphi\frac{\partial\Phi}{\partial x^\sigma}\gamma_\sigma+2\frac{g_3}{\kappa^2}\frac{\partial\varphi}{\partial x^\rho}\frac{\partial\Phi}{\partial x^\sigma}\gamma_{\rho\sigma}\right]\tau_-+c.c.\right\}\psi, \tag{4}$$

where $\kappa=\mu c/\hbar$ and $\gamma_{\rho\sigma}=i(\gamma_\rho\gamma_\sigma-\gamma_\sigma\gamma_\rho)$, τ_- being an operator that transforms an electron into a neutrino. The probability per second of μ-decay in which the electron is produced with a momentum in the interval p_e, p_e+dp_e is then proportional to:

$$dp_e\left\{|g_1|^2 f_1\left(\frac{p_e}{\mu c}\right)+|g_2|^2 f_2\left(\frac{p_e}{\mu c}\right)+|g_3|^2 f_3\left(\frac{p_e}{\mu c}\right)\right.$$
$$\left.+\frac{i}{2}(g_1g_2{}^*-g_2g_1{}^*)\cdot f_{13}\left(\frac{p_e}{\mu c}\right)\right\}. \tag{5}$$

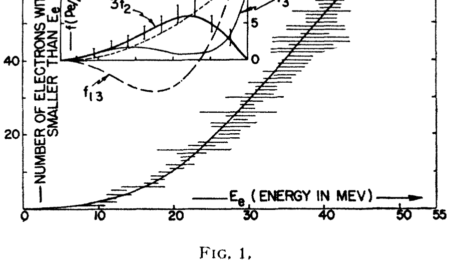

FIG. 1.

The functions f are shown, for $\mu_0=0$ as consistent with the experimental results,[6,7] in the upper left part of Fig. 1; the experimental points of Anderson and co-workers[7] are also plotted in an arbitrary scale. It is seen that the only one of the simple couplings which gives a spectrum in agreement with the experimental points is the one in g_2.[8] This agreement may be emphasized if one compares the integral spectrum ($\sim E_e{}^3[2\mu c^2-3E_e]$) with the experimental points, as is done in the lower part of Fig. 1.

If we consider now the capture of a μ-meson by a nucleus we calculate the nuclear excitation as in case of spin $\frac{1}{2}$,[1] using for the interaction of μ, μ_0-mesons with nucleons an expression similar to (4); we then obtain a spectrum of nuclear excitation very similar to that of the case of spin $\frac{1}{2}$ and, then, also the result that the probability for star production is very small.[9]

One then concludes that the possibility of spin zero for μ_0-mesons is in good agreement with the experimental results and should not be disregarded for the moment.

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[1] J. Tiomno and J. A. Wheeler, Rev. Mod. Phys. **21**, 144, 153 (1949).

[2] R. F. Christy and S. Kusaka, Phys. Rev. **59**, 414 (1941).

[3] The possibility of a coupling of μ, μ_0 with the electron-neutrino field, linear in each mesonic field is easily excluded in view of the impossibility of making the process (2) significantly more probable, then:

$$\mu\rightarrow e+\nu\rightarrow e+\nu+h\nu.$$

[4] We exclude terms with two time derivatives of ϕ, φ and ψ as they lead to difficulties in the application of the usual Hamiltonian formalism.

[5] Terms with derivatives of ψ are, to first order, equivalent to terms of the kind considered in (4).

[6] C. M. G. Lattes, Phys. Rev. **75**, 1468 (1949).

[7] Leighton, Anderson, and Seriff, Phys. Rev. **75**, 1432 (1949).

[8] A rough agreement can also be obtained with $g_3=0$, $g_1=ig_3$.

[1] It should be pointed out that assuming that the interaction of spinless μ-mesons with nucleons is through an intermediate κ-meson we obtain a lifetime for the $\pi-\mu$-decay of the order of 10^{-8} sec. as shown by A. S. Lodge (Nature **161**, 809 (1948)), R. Latter and R. F. Christy (Phys. Rev. **75**, 1459 (1948)) and others.

Analysis of Delayed Coincidence Counting Experiments

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THE use of the delayed coincidence method for measuring short half-lives by several investigators[1-4] makes a reexamination of the basis of the experiment desirable. The coincidence counting rate *versus* delay curves exhibit two regions. The first is affected by the random delays in the counter itself, and the second is a pure exponential decrease determined by the radioactive decay. Van Name[3,5] analyzed the combination of these effects by assuming a triangular distribution for the delays in the counter but found it necessary to divide the range of artificial delays into six regions. A Gaussian distribution will be used here, and a fairly simple relation will result.