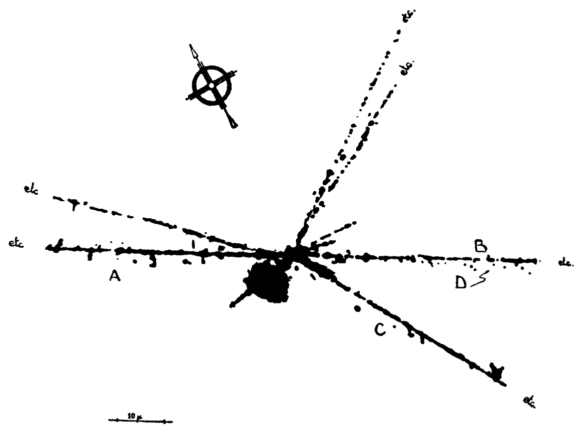

FIG. 1. A microphotograph of a star with three outgoing heavy particle tracks.

sion, the increase of the number of δ-rays per 100μ is higher by 100 percent in the last 600μ of the track than in the 600μ nearest to the star center. The particle A is therefore near the end of its range. Using the criterion of δ-ray counts for NTB plates we find for this particle $Z \cong 6$ a minimum energy of 560 Mev and a momentum of 3510 Mev/c. The energy and momentum of particle B have been evaluated approximately by the following considerations. The faint track D has a grain density (estimated from β-particles visible near the star) corresponding to a proton of about 140 Mev. To permit approximate calculations it is assumed that the particle B and the particle D have equal energy, for the alternative assumptions of equal momentum and equal energy per nucleon lead to results not consistent with δ-ray count and grain density. The δ-ray count of particle B corresponds then to a value of $Z \cong 3$. A minimum energy for particle C may be found by choosing the smallest Z consistent with the δ-ray count and by adding to the observed length of the track an amount sufficient to bring the δ-ray count down to zero. The $Z=4$ or 5 for particle C.

To estimate the energy and momentum of the incident particle only the kinetic energy of the particles A, B, C, and D is taken into account and the energy of the other particles of the star and all binding energies are neglected.** It is assumed that these low energy particles are isotropically distributed and contribute nothing to the momentum. The estimated minimum values of energy and momentum of the particles A, B, and C are given in Table I.

If the particle C is assumed to have $Z=5$, the sum of the energies is 1060 Mev and the resultant momentum is 955 Mev/c. If it is assumed also that the kinetic energy of the incident particle is 1060 Mev, the energy transfer is of the same order as the momentum transfer indicating a relativistic particle passing through the nucleus. On the other hand if 1060 Mev is taken to be the total energy of the incident particle, the energy and resultant momentum are compatible with the assumption that a τ-meson has been captured by the nucleus. Then from

$$E_{\text{total}} = E_{\text{kinetic}} + MC^2$$

and

$$P = (1/c)((E_{\text{total}})^2 - (MC^2)^2)^{\frac{1}{2}}$$

TABLE I. Estimated charge, energy, and momenta of the particles A, B, C, and D in the star of Fig. 1.

Track	Delta-rays per 100μ	Z	Energy (Mev)	Momentum (Mev/c)
A	13 (near star center) 27 (at end of track)	6	560	3500
B	6	3	140	1260
C	9	5	220	2040
D		1	140	530

the rest energy of the meson is found to be ~ 460 Mev and the mass ~ 880 electron masses. If particle C is assumed to have $Z=4$ instead of 5, the meson mass $= \sim 1170$ electron masses.

The total charge freed in the star is $\sim 25e$ and the exploding atom could be bromine or silver. However, it is not impossible that the explosion occurred in a Bi atom for the black spot shown in Fig. 1 is a Bi speck. The star is an illustration of Perkin's "Fission Hypothesis"[7] assuming that heavy splinters break away from the nucleus if the energy of the incident particle is comparable with the binding energy of the nucleus.

* Work done under subcontract to Brookhaven National Laboratory which is operated under a prime contract with the AEC.

** The line of reasoning which follows might be changed if minimum ionization particles were present. However, in our experience such particles are frequently accompanied by particles of lower energy observable in this emulsion.

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The Disintegration Energy of Al^{29} *

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THE particular stability of nuclear systems with proton or neutron numbers 2, 8, 10, 20, 50, 82, and 126 has been explained by the occurrence of closed shells. The configurations proposed are, up to Ca^{40}: $(1s)^2(2p)^6(2s)^2(3d)^{10}$ (e.g., Feenberg and Hammack,[1] Nordheim[2]). No shell closure would occur between Ne^{20} and Ca^{40} and a regular variation of masses and decay energies with Z is expected for a sequence of nuclei of the same symmetry. A serious deviation from this behavior has been found by Bleuler and Zünti[3] in the case of the transition $Al^{28}-Si^{28}$. The upper curve of Fig 1, essentially copied from a note by Barkas,[4] shows the disintegration energies of the sequence in question. The value for Al^{28} seems about 1.3 Mev too high. Comparison of the masses of Al^{28} and Si^{28} with the values calculated by Barkas[5] indicates that the anomaly is due, most probably, to a low mass, i.e., a high binding energy, of Si^{28}. Closure of a shell at $Z=14$ could be expected, if an alternate configuration scheme, based on strong spin-orbit coupling, is assumed (Haxel, Jensen, and Suess,[6] Mayer[7]). The same shell closure should manifest itself in the decay $Al^{29}-Si^{29}$. However, the value of 2.5 Mev given by Bethe and Henderson[8] for the upper limit of the β-spectrum of Al^{29}, with no γ-radiation, would be only slightly higher than expected from

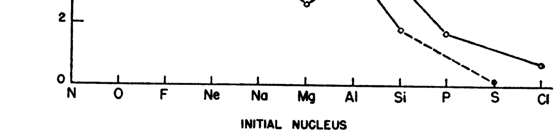

FIG. 1. Decay energies of nuclei of the same isotopic spin $T_\xi = (N-Z)/2$. Upper curve: N^{16} to Cl^{36}, lower curve: N^{17} to S^{35}.

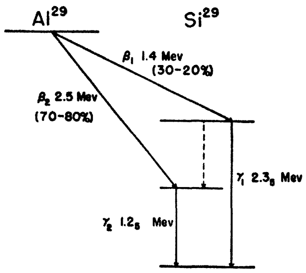

FIG. 2. Decay scheme of Al^{29}.

the sequence of similar nuclei. It seemed interesting, therefore, to redetermine the decay scheme of Al^{29}.

Al^{29} was produced by bombarding Mg with the 18-Mev α-particles of the Purdue cyclotron. The absorption curves for single counts and $\beta\gamma$-coincidences were obtained by following, for each absorber, the decay curve together with that for a standard absorber and analyzing them into the 2.30-min. and 6.56 ± 0.06-min. periods of Al^{28} (from Mg^{25}) and Al^{29}. Contrary to previous measurements,[8] the absorption curve shows a γ-background. The analysis indicates a complex β-spectrum, consisting in the simplest case of two components of 2.5 Mev and 1.4 Mev ($\sim$30 percent). All β-transitions are followed by γ-radiation: the ratio of $\beta\gamma$-coincidences to single β-counts is constant from about 200 mg/cm^2 to at least 1000 mg/cm^2; its value indicates (after calibration of the arrangement with Na^{24} that the 2.5-Mev β-spectrum is followed by a γ-ray of 1.2 ± 0.2 Mev. For thinner absorbers $N_{\beta\gamma}/N_\beta$ increases slightly, corresponding to the higher γ-energy coupled with the low energy partial β-spectrum. In addition, the γ-ray energies were measured directly by coincidence absorption of the secondary electrons. Two components of 2.3_5 Mev ($\sim$20 percent) and 1.2_5 Mev can be distinguished.

The decay scheme compatible with these data is given in Fig. 2. Both β-transitions are allowed with $ft=1.6\cdot10^5$ (2.5 Mev) and $2\cdot10^4$. Cascade γ-radiation, with an intensity less than 10 percent, cannot be excluded. While the decay scheme might be subject to modifications, the total disintegration energy of 3.75 ± 0.25 Mev seems well established. The lower curve of Fig. 1 shows the decay energies of the nuclei N^{17} to S^{35}. The value for Al^{29} is seen to be about 1.7 Mev higher than expected from the neighboring members of the sequence. This may be interpreted as confirming evidence for an especially stable structure of Si^{28} (and Si^{29}), due possibly to a shell closure at $Z=14$.

* Supported by the ONR.

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On a New Conception of the Interaction between Charges and Electromagnetic Field

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FOR the past fifteen years, I have tried to develop a form of quantum electrodynamics which I have named "wave mechanics of the photon." This theory has been set forth in several books.[1] In 1935, at the beginning of these investigations, a hypothesis was emphasized in order to avoid an infinite value for the self-energy of a charged particle. The wave mechanics of the photon discriminates between the coordinates of the charge X, Y, Z (vector $\mathbf{R}$) and the variables of the field x, y, z (vector $\mathbf{r}$). For the interaction between charge and field in a frame of reference in which the particle is at rest, the following expression is found:

$$\int\int V(\mathbf{r})\rho(R)\delta(\mathbf{r}-\mathbf{R})d\mathbf{r}d\mathbf{R}, \tag{1}$$

where δ is the Dirac function. This expression gives, as usual, an infinite value for the proper energy of the charge. I have suggested[2] that we might replace the δ-function in (1) by a function $f(\mathbf{r}-\mathbf{R})$ in the form of a very sharp, but not infinitely sharp, needle. This substitution, which would express a kind of uncertainty for the point of application of the field on the charge, would lead to a finite value of the self-energy.

Unfortunately, this idea meets difficulties from the viewpoint of relativistic invariance. Let us adopt the multi-temporal theory which introduces distinct times t and T for the field and the charge. The correct relativistic variance of the expression (1) is shown by the fact that one can write it in *any* reference frame:

$$\left|\int\int\sum_{\mu=1}^{4} A_\mu(x,y,z,t)j_\mu(X,Y,Z,T)\left(-\frac{1}{4\pi c}\frac{\partial D(0)}{\partial t}\right)\times dxdydzdXdYdZ\right|_{t=T}, \tag{2}$$

where $D(0)$ is the form for $k_0=0$ of the invariant singular function

$$D(k_0)=-\frac{1}{2\pi^2}\int\frac{\sin[kc(t-T)-\mathbf{k}(\mathbf{r}-\mathbf{R})]}{k}d\mathbf{k} \tag{3}$$

with $k^2=|\mathbf{k}|^2+k_0^2$. Indeed, for all values of k_0

$$\left|\frac{1}{c}\frac{\partial D(k_0)}{\partial t}\right|_{t=T}=-4\pi\delta(\mathbf{r}-\mathbf{R}). \tag{4}$$

But if we will substitute for the δ-function in (1) a function in the form of a sharp needle, we cannot see how the correct relativistic variance can be preserved.

I have been recently lead to a new investigation of this problem by recent papers of R. P. Feynman. Guided in my choice by the suggestions of Feynman and others,[3] I will start from the following form of Wentzel potentials (in non-rationalized units):

$$A_\mu(x,y,z,t,X,Y,Z,T)=-\epsilon\int_{-\infty}^{X_\mu}[D(0)-D(k_0)]dX_\mu, \tag{5}$$

ϵ being the electric charge of the particle. Then we have

$$\Box A_\mu=-k_0^2\epsilon\int_{-\infty}^{X_\mu}D(k_0)dX_\mu;\quad \Sigma_\nu\frac{\partial A_\nu}{\partial x_\nu}=\epsilon[D(0)-D(k_0)]. \tag{6}$$

Starting from the usual definition of the field in terms of potentials, we can easily find for the "electric field" $\mathbf{E}$ the relation

$$\mathrm{div}\mathbf{E}=-\frac{\epsilon}{c}\frac{\partial}{\partial t}[D(0)-D(k_0)]+k_0^2\epsilon\int_{-\infty}^{cT}D(k_0)d(cT). \tag{7}$$

If one makes $T=t$ (equalization of the times), one finds by (4)

$$\mathrm{div}\mathbf{E}=k_0^2\epsilon\left|\int_{-\infty}^{cT}D(k_0)d(cT)\right|_{T=t}. \tag{8}$$

The calculation in a frame of reference where the charge is at rest gives

$$\left|\int_{-\infty}^{cT}D(k_0)d(cT)\right|_{T=t}=\frac{\exp[-k_0|\mathbf{r}-\mathbf{R}|]}{|\mathbf{r}-\mathbf{R}|}. \tag{9}$$

Therefore, we see by (8) and (9) that we can replace the point charge ϵ localized at $\mathbf{R}$ by a continuous distribution of total charge ϵ with the density

$$\sigma=\epsilon f(\mathbf{r}-\mathbf{R})=\frac{\epsilon k_0^2}{4\pi}\frac{\exp[-k_0|\mathbf{r}-\mathbf{R}|]}{[\mathbf{r}-\mathbf{R}]}. \tag{10}$$

It is noteworthy that σ has the form of a Yukawa potential. Moreover, one can easily verify that the electrical distribution (10) gives at the point $\mathbf{r}$ ($\mathbf{R}$ being at the origin) the scalar potential

$$V(r)=\epsilon\frac{1-\exp[-k_0r]}{r} \tag{11}$$