in the proper energy channels were measured with and without GM counter umbrella in anticoincidence.

The results showed an exponential time distribution with a mean life of $2.2\pm0.05$ $\mu$sec.[1] The large area of the detector permitted collection of the cosmic-ray data in counting times of about 30 minutes for the complete determination.

In the course of this work, several applications to problems of current interest were made. Cylindrical inserts, empty and open at the top, were placed in the large counter. A survey of native radioactive contamination of a number of shielding materials placed in the insert revealed that samples of stainless steel were very clean; mild steel was slightly active; while lead, tap water, and photomultiplier tubes were considerably contaminated. A live dog was lowered into the insert and counted before and after injection of a solution containing $10^{-7}$ curies of radium. It was concluded that a radium content of about $5\times10^{-9}$ curies could have been detected. By doubling up, a human being could be lowered into the counter which covered almost all of the solid angle. A number of people, men and women, were thus counted, with counting rates well above background. A water "human phantom" was made and a potassium salt dissolved in it. A counting efficiency of 10 percent for $K^{40}$ in this geometry was found. The counting rates from the human beings agreed well in most cases with the rate expected from the potassium in their bodies. Studies of neutron shielding external to the detector were also done.

It is, of course, clear that phenomena which are distinguished by two or more events in delayed coincidence can be considered for study by means of such large detectors, and various inserts can be employed where needed, for instance, in the individual counting of the two gamma-rays from positron annihilation. Detailed discussions of investigations with the large detectors will be published in due course. The authors wish to thank L. Brown, R. Schuch, and Captain W. A. Walker for their assistance in the construction and testing of the detectors, C. W. Johnstone for the design of the electronic equipment, and T. J. White and D. Carter for help in computations.

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[1] This value is in agreement with the results of E. P. Hincks and W. E. Bell, Phys. Rev. **84**, 1243 (1951); **88**, 168 (1952).

## The Mechanism of the Reaction $O^{16}+h\nu\rightarrow 4He^4$†

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ALTHOUGH $\sigma(h\nu)$ for the reaction $O^{16}(\gamma,\alpha)3\ He^4$ has recently been reported[1] for quanta up to 70 Mev on the basis of 700 "oxygen stars" observed in nuclear emulsions, little is known about the mechanism of this reaction and, in particular, whether and which excited states of $C^{12}$ and $Be^8$ are involved as intermediate steps in a cascade:

$$\text{(a) } O^{16}+h\nu\rightarrow C^{12*}+\alpha_1;\quad \text{(b) } C^{12*}\rightarrow Be^{8*}(Be^8)+\alpha_2;$$
$$\text{(c) } Be^{8*}(Be^8)\rightarrow\alpha_3+\alpha_4. \quad (1)$$

For $h\nu<23$ Mev, Goward and Wilkins[2] have concluded from 66 stars that ~50 percent of the events lead to the ground state of $Be^8$ via a 9.7-Mev state in $C^{12}$, while Livesey and Smith[3] reported a change of mechanism for $h\nu>23$ Mev on the basis of 83 events. The behavior around 25 Mev is of particular interest, as it is there that the selection rules imposed by charge independence[4] predict a radical change in mechanism.

We present here some preliminary results derived from 230 stars observed in 400-$\mu$ Ilford $E1$ plates irradiated with 48-Mev bremsstrahlung. The insert in Fig. 1 shows the energy distribution $N(E_T)$ of these events ($E_T=\Sigma_1^4 E\alpha_i=h\nu-14.43$ Mev). There is some indication of peaks corresponding to the "level absorption"

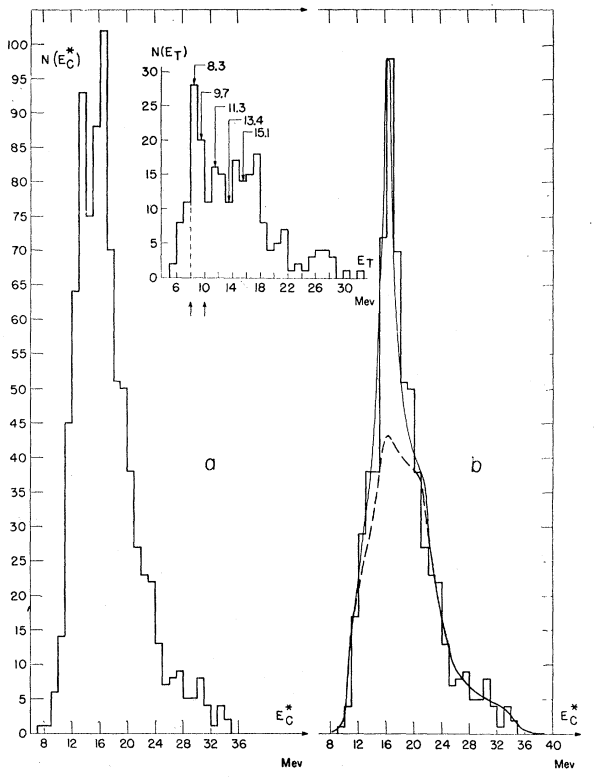


FIG. 1. (a) Experimental $E^*$ distribution from events with $E_T>8$ Mev; (b) experimental $E^*$ distribution (histogram) from events with $E_T>10$ Mev and calculated distribution curve for $E_C^*=16$ Mev, $E_{Be}^*=3$ Mev. Insert: $N(E_T)$ of analyzed events.

as reported by other workers[1,3] with better statistics; the location of peaks given by reference 1 is indicated by arrows.

For a cascade mechanism (1) proceeding via a $C^{12}$ level of $E_C^*$ excitation, one has

$$E_C^*=h\nu-|B_a|-4E_1/3=E_T+|B_b|-4E_1/3, \quad (2)$$

where $E_1$ = energy of $\alpha_1$, $B_a$ = binding energy in step $a$, $B_b$ = binding energy in step $b$. Applying (2) to *all four* $E_i$ ($i=1,\cdots4$) of any event a significant $E_C^*$ and three spurious $E_C^*$ values are obtained. The distribution $N(E_C^*)$ of these $4n$ $E_C^*$ values from $n$ events will exhibit a peak (or peaks) at the $E_C^*$ of the level(s) involved, superimposed on a continuum corresponding to $\alpha_2$, $\alpha_3$, and $\alpha_4$. Knowing $N(E_T)$, the shape of this continuum can be calculated from the dynamics of the problem upon assuming values for $E_C^*$ and $E_{Be}^*$. Figure 1(a) shows $N(E_C^*)$ for 209 stars with $E_T>8$ Mev (i.e., $h\nu>22.4$ Mev). It displays a very prominent peak at $E_C^*\backsimeq16$ Mev and a minor one at $E_C^*\backsimeq13$ Mev, while nothing corresponding to a 9.7-Mev level appears. Equation (2) shows that $E_T\gtrsim8.7$ Mev+Coulomb barrier is required to excite a level at 16.0 Mev; we have therefore redrawn the distribution $N(E_C^*)$, as shown by the histogram in Fig. 1(b), considering now only events with $E_T>10$ Mev. This histogram shows a single peak near 16 Mev, while the peak at 13 Mev has disappeared. An $N(E_C^*)$ histogram for the events with $8\lesssim E_T\lesssim10$ Mev, not reproduced here, confirms that a level at about 13 Mev (probably the known[5] level at 13.2 Mev) participates strongly in this energy range.

The dotted curve in Fig. 1(b) is the continuum distribution to be expected if one assumes $E_C^*=16$ Mev, $E_{Be}^*=3$ Mev, and the absence of angular correlations in either step of the cascade. Superimposing a peak corresponding to a 16-Mev level of 1.8-Mev *experimental* half-width leads to the full drawn curve in excellent agreement with experiment.

Assuming this agreement to signify that the reaction proceeds indeed, for $h\nu > \sim 25$ Mev, via $C^{12}$ and $Be^{8}$ levels near the above energies, we are forced to conclude that it suddenly ceases to go through the levels involved at lower energies which should energetically be favored.

This situation is easily understood[4] if one assumes (a) $E1$ absorption, in $O^{16}$, in this energy range, (b) charge-independence of nuclear forces, and (c) one or more levels of $T=1$ in $C^{12}$ near 16 Mev. Assumption (c) is plausible, inasmuch as the carbon levels[5] at 15.09 Mev and 16.07 Mev correspond probably to the ground and first excited states of $B^{12}$, respectively. $E1$ absorption in $O^{16}$, a self-mirrored nucleus, should lead only to $T=1$ states, which cannot rapidly decay by $\alpha$'s except to $T=1$ levels in $C^{12}$. The latter can decay by $\alpha$-emission through small $T=0$ "admixtures," if no other particle emission competes.

Six events appear to go by a cascade mechanism as predicted in reference 4 ($E_C^* \cong 26.5$ Mev, $E_{Be}^* \cong 17$ Mev); 3 of these are, however, also compatible with $E_C^* = 16$ Mev.

The present data do not enable one to resolve the peak near 16 Mev into two peaks separated by only 1 Mev, nor to determine the anomalously small *true* width which these ought to have. This would be required to prove fully the correctness of our explanation.

A further problem is raised if more detailed experiments confirm that for $8 < E_T < 10$ Mev the level at 13 Mev is strongly preferred to lower-lying $C^{12}$ levels. Since for $E < 15$ Mev all levels have $T=0$, this preference cannot be attributed to charge independence. It is as mysterious as the preferential $\alpha$-decay of the 16.07-Mev state to the 3-Mev level of $Be^{8}$, assumed here and observed in $C^{12}(\gamma, \alpha)Be^{8}$,[6] and other reactions.[5]

An interesting consequence of our hypotheses is that the $O^{16}$ levels above 25 Mev suggested by $\sigma(h\nu)$ of reference 1 ought to have $J=1^-$, $T=1$.

We hope to present a more detailed report, based on improved statistics, in the near future.

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## Movable Critical Points of a Nonlinear Wave Equation

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A MOVABLE critical point of nonlinear differential equation is a branch point or an essential singularity, the position of which depends on the constants of integration and so is not fixed. Since the presence of movable critical points greatly complicates the solution of an equation, it is of some interest to see if known necessary conditions for their absence[1] are violated in a particular case. We consider here the nonlinear wave equation discussed by Schiff[2] and Thirring:[3]

$$\Box\phi - \kappa^2\phi - \eta\phi^3 = 0. \tag{1}$$

Both Schiff and Thirring are satisfied with approximate solutions, because of the impossibility of separating variables. Heisenberg[4] considers a simplified form of Eq. (1), in which a single Cartesian coordinate $x$ and the time $t$ are the independent variables. He finds Lorentz-invariant solutions by introducing a single new variable $s = t^2 - x^2$. With $\eta = 0$, he shows that Eq. (1) reduces to Bessel's equation of order zero in the variable $\kappa s^{\frac{1}{2}}$.

With $\eta \neq 0$, we now show that Eq. (1) is not free of movable critical points. The substitution $\phi = (8s/|\eta|)^{\frac{1}{2}} f(s)$ puts Eq. (1) in one of Ince's standard forms:[5]

$$f'' = -2f'/s \pm 2f^3 - (1+\kappa^2 s)f/4s^2, \tag{2}$$

where the upper sign is for $\eta < 0$ and the lower sign for $\eta > 0$. It is apparent that the necessary condition for the absence of movable critical points is not satisfied if $\eta > 0$. With $\eta < 0$, the condition is satisfied only if there exists a function $q(s)$ such that:[5]

$$f'' = -3qf' + 2f^3 - (q' + 2q^2)f. \tag{3}$$

Comparison of Eqs. (2) and (3) shows that no such function $q(s)$ exists. There is then no existence proof for the solution of Heisenberg's one-dimensional Lorentz-invariant simplification of Eq. (1).

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## Synchrocyclotron Production and Properties of Magnesium 28†

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SHELINE and Johnson[1] have recently reported producing $Mg^{28}$ with a half-life of 21.3±0.2 hours by the reactions $Mg^{26}(\alpha, 2p)Mg^{28}$ and $Si^{30}(\gamma, 2p)Mg^{28}$. Prior to learning of these results, we had bombarded a target of silicic acid with 350-Mev protons in the Carnegie Institute of Technology synchrocyclotron in a search for the product of the reaction $Si^{30}(p, 3p)Mg^{28}$. We confirm the identification of this nuclide.

The target consisted of 2 grams of silicic acid wrapped in aluminum foil. Ten milligrams of magnesium carrier were added, and the silica was leached out four times with 6*N* NaOH. The residue was dissolved in HCl, buffered to *p*H∼5 with acetic acid and sodium acetate, and repeatedly scavenged by addition of aluminum carrier and precipitation with 8-hydroxyquinoline. Magnesium was precipitated by the addition of ammonia and 8-hydroxyquinoline, dissolved with $HNO_3$, and precipitated twice as $MgNH_4PO_4 \cdot 6H_2O$.

We derive a half-life for $Mg^{28}$ of 22.1±0.3 hours from a decay curve covering over seven half-lives. Since this differs significantly from the value of Sheline and Johnson, we mention that the nonlinearity corrections for the Geiger counter used were determined carefully by the method of multiple paired sources.[2] Aluminum fractions, separated from the magnesium as the 8-hydroxyquinolate, exhibited a 2.4-minute half-life characteristic of $Al^{28}$.

Aluminum absorption curves of the $Mg^{28}$–$Al^{28}$ equilibrium mixture could be resolved into only two electronic components of ranges 65 and 1450 mg/cm². The latter corresponds well with the 2.86-Mev[3] beta of $Al^{28}$; and the former, which represents a maximum beta-energy of 0.3 Mev, we assign to $Mg^{28}$.

Both $Mg^{28}$ and $Al^{28}$ have a comparative lifetime ($ft$) of $\sim 10^5$ seconds, corresponding to allowed transitions. The unobserved ground-state transition between $Al^{28}$ and $Si^{28}$ is presumably second forbidden, and the ground-state transition between $Mg^{28}$ and $Al^{28}$ would be expected to be similarly forbidden. Hence the decay of $Mg^{28}$ must be to an excited state or states of $Al^{28}$, with consequent gamma-emission. Accordingly, we examined the gamma-radiation from the equilibrium mixture with a NaI(Tl) scintillation spectrometer. In addition to the known 1.78-Mev[3] gamma of $Al^{28}$, several other gammas were found to be present, with energies extending to at least 2.6 Mev. The total disintegration energy of $Mg^{28}$ thus appears to be at least 2.9 Mev. $Al^{28}$ is known[4] to have about a dozen excited states within ∼3 Mev of its ground state. Further work is needed to establish the complex disintegration scheme; we have been forced to discontinue our experiments temporarily by a shutdown of the cyclotron.

In each of two one-hour bombardments the yield of $Mg^{28}$ was about $8 \times 10^5$ disintegrations per minute. The circulating current