production of stars, show clearly that the probability of the emission of many nucleons is significant. Further experiments are in progress with other reactions which it is hoped will clarify the mechanism of nuclear reactions in this energy region.

This work was supported by the Atomic Energy Commission under Contract W-7405-Eng-48 with the University of California.

[1] This deflector system will be described in detail in a forthcoming paper by Dr. Wilson M. Powell.

Erratum: Spectral Location of the Absorption Due to Color Centers in Alkali Halide Crystals

[Phys. Rev. 72, 341 (1947)]

HENRY F. IVEY
Research Laboratory, Westinghouse Electric Corporation, Bloomfield, New Jersey

REFERENCE (6) should read: E. Mollwo, as reported by Pohl in reference (*g*). It now appears as ". . . reference (3)."

In the table, the reference for the value 5700 for the R_2-band of KF should be (*d*). It now appears as (6).

In the table, the reference for the value 7200 for the *F*-band of RbBr should be (*f*). It now appears as (8).

In the heading of the second column of the table, "Inter-Ionic Salt Distance," the word "Salt" should be removed. This word should be the heading of the first column, but its omission is not confusing.

Excitation Curve for the Reaction $C^{12}(p, pn)C^{11}$ up to 140 Mev

WARREN W. CHUPP AND EDWIN M. MCMILLAN
Radiation Laboratory, University of California, Berkeley, California

September 22, 1947

THE work of Helmholz, McMillan, and Sewell[1] and Serber[2] has shown that neutrons are stripped off of deuterons when they strike an internal cyclotron target; one naturally expects a similar process in which protons are set free. These protons, having a mean energy half that of the deuterons, will move in circles passing near the center of the cyclotron and with the expected energy spread resolved as in a mass spectrograph. Their distribution is being studied by Chupp, Gardner, and Taylor,[3] and the work reported in this letter shows that their intensity is quite adequate for nuclear experimental work. Stacks of carbon plates enclosed in copper houses, and with suitable defining slits in front, were placed as shown in Fig. 1, the houses being below the level of the circulating deuterons and tilted upward at a proper angle. After exposure to the proton beam, the carbon plates were taken out and their activities (20.5-min. C^{11}) measured on a G-M counter; the plot of the activities against position in the stack gives directly the excitation curve on a range scale.

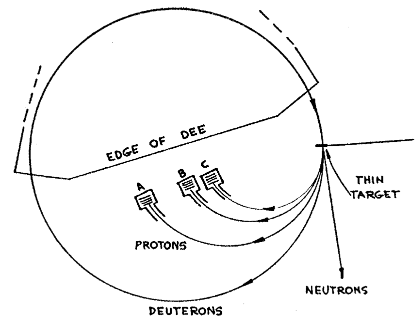

FIG. 1. Schematic diagram of experimental set-up in the 184-in. cyclotron. *A*, *B*, and *C* indicate the three positions of the houses containing the carbon plates. These are below the level of the deuteron orbits.

A series of four runs was made with the plates in position *C*, where the incident proton energy was found to be 65 Mev. The carbon plates were disks $1\frac{11}{16}$-in. diameter by $\frac{1}{32}$ in. thick, with a surface density of 137 mg/cm². In order to establish the end of the range, plates of compressed boric acid having the same stopping power were interposed between some of the carbon plates; the resulting activity formed by $B^{11}(p, n)C^{11}$ with a low threshold gives a fiducial mark from which the range can be found within the resolving power of this experiment (about $\pm\frac{1}{32}''$ from the energy spread admitted by the slit system). In Fig. 2, the points corresponding to energies below 65 Mev come from this series. A small neutron background of about 3 percent was subtracted from the carbon activities. Each point is a mean of all the measurements, and the spread found in individual values is of the same order as the irregularities in the curve.

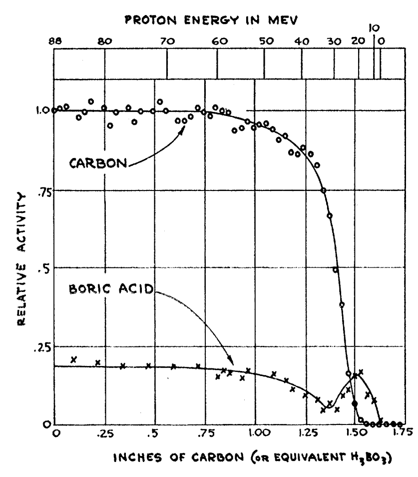

FIG. 2. Excitation curve for the C^{11} activity induced in carbon plates by protons entering at the left. Each point is plotted at a position corresponding to the surface of the plate on which the activity was measured. The lower curve represents the C^{11} activity found in H_3BO_3 plates between some of the carbon plates, and was used to find the end of the range. Points above 65 Mev come from one run and those below 65 Mev from four runs averaged together; these were adjusted in height to fit at 65 Mev. Another run extending the curve to 140 Mev is not included, since it indicates a constant cross section. One inch of carbon corresponds to 4.38 g/cm².

Another run was made in position B, where the energy was 88 Mev. This provides the points in Fig. 2 from 88 to 65 Mev. Finally, a run in position A was made, using $2''\times 3''\times \frac{1}{4}''$ carbon plates; here the neutron background was relatively large (about 40 percent) because the number of protons was small, but the accuracy was sufficient to show that the cross section does not vary appreciably in going from 88 up to 140 Mev. This last run was not included in the plot.

The striking feature of this result is that there is little if any variation in the $C^{12}(p, pn)C^{11}$ cross section between 60 and 140 Mev. This is not consistent with the picture of proton capture followed by pn evaporation, because the competition of other reactions at high excitation energies would reduce the cross section rapidly. One must assume a non-capture excitation or a (p, n) exchange with roughly constant energy transfer, followed by evaporation of a single neutron or proton. Dr. Serber has pointed out[4] that this is a reasonable assumption in this energy range.

The activity in the boric acid is itself of some interest. The (p, n) reaction in B^{11} gives a peak near the end of the range, as expected for that type of reaction; the second rise at higher energy is attributed to reactions forming C^{11} from oxygen, since its magnitude is consistent with the activity observed in BeO traversed by the same proton current.

This work was done under the auspices of the Atomic Energy Commission, under Contract No. W-7405-Eng-48.

[1] A. C. Helmholz, E. M. McMillan, and D. Sewell, Phys. Rev., to be published.
[2] R. Serber, Phys. Rev., to be published.
[3] W. W. Chupp, E. Gardner, and T. B. Taylor, to be published.
[4] R. Serber, to be published.

On Quantized Space-Time

C. N. Yang
Department of Physics, University of Chicago, Chicago, Illinois
September 15, 1947

RECENTLY Snyder[1] has developed a theory of quantized space-time that is invariant under Lorentz transformations. The theory is, however, not invariant under translations. Indeed, as he has pointed out, to make the theory invariant under translations one must have space-time coordinates forming a continuum.

It does seem desirable, however, to have an invariant theory under a wider group of transformations than the Lorentz transformations. (E.g., we may want to have homogeneity as well as isotropy in space-time.) This can be accomplished by proposing that space-time is curved.

As an example let us consider a de Sitter universe

$$-x_0^2+x_1^2+x_2^2+x_3^2+\xi^2=R^2, \tag{1}$$

which is a pseudosphere in a five-dimensional flat space: x_0, x_1, x_2, x_3, ξ. The group of linear transformations that leaves the quadratic form $-x_0^2+x_1^2+x_2^2+x_3^2+\xi^2$ unchanged could be approximated by the product of the ordinary Lorentz group and the group of translations, for points on the pseudosphere in the region $|x_0|\ll R$, $|x_i|\ll R$. If we define $L_i/\hbar$, $M_i/\hbar$, and $Rp_0/\hbar$ and $Rp_i/\hbar$ as the nuclei of these transformations, we would get the angular- and linear-momenta operators in the de Sitter universe. The p's are given by

$$\begin{aligned} p_0&=i\hbar\frac{\xi}{R}\frac{\partial}{\partial x_0}+i\hbar\frac{x_0}{R}\frac{\partial}{\partial \xi},\\ p_i&=-i\hbar\frac{\xi}{R}\frac{\partial}{\partial x_i}+i\hbar\frac{x_i}{R}\frac{\partial}{\partial \xi}.\end{aligned} \tag{2}$$

They satisfy

$$L_i=\xi(x_jp_k-x_kp_j)/R. \tag{3}$$

The commutators involving the p's are

$$[p_i,\, p_j]=i\hbar L_k/R^2,$$

and

$$[x_i,\, p_j]=i\hbar\xi\delta_{ij}/R. \tag{4}$$

Those involving the L_i, M_i, and x_μ's are as usual.

The above is, however, not the only theory that is invariant under the Lorentz transformations in five dimensions. We shall propose, in general, that x_0, x_1, x_2, x_3, ξ be Hermitian operators, and that after a Lorentz transformation in five dimensions they can be brought back to their original forms by a unitary transformation. This means that the nuclei of the unitary transformations, which we define to be $L_i/\hbar$, $M_i/\hbar$, and $Rp_0/\hbar$, and $Rp_i/\hbar$, still satisfy the same commutation relations (4). The commutation relations between the operators x_0, x_1, x_2, x_3, ξ are not fixed by the requirement of invariance. If we propose that they are given as follows,

$$\begin{aligned} [x_i,\, x_j]&=ia^2L_k/\hbar, & [x_0,\, x_i]&=ia^2M_i/\hbar,\\ [\xi,\, x_i]&=ia^2Rp_i/\hbar, & [\xi,\, x_0]&=ia^2Rp_0/\hbar,\end{aligned} \tag{5}$$

it is evident that the 15 operators $L_i/\hbar$, $M_i/\hbar$, $Rp_\mu/\hbar$, x_μ/a and ξ/a satisfy the same commutation relations as the nuclei of the group of Lorentz transformations in six dimensions with the basic quadratic form $-\eta_0^2+\eta_1^2+\eta_2^2+\eta_3^2+\eta^2+\zeta^2$. So a possible solution is

$$\begin{aligned} L_i&=i\hbar\left(\eta_k\frac{\partial}{\partial\eta_j}-\eta_j\frac{\partial}{\partial\eta_k}\right),\\ M_i&=i\hbar\left(\eta_0\frac{\partial}{\partial\eta_i}+\eta_i\frac{\partial}{\partial\eta_0}\right),\\ p_0&=\frac{i\hbar}{R}\left(\eta\frac{\partial}{\partial\eta_0}+\eta_0\frac{\partial}{\partial\eta}\right), \quad p_i=\frac{i\hbar}{R}\left(\eta\frac{\partial}{\partial\eta_i}-\eta_i\frac{\partial}{\partial\eta}\right),\\ x_0&=ia\left(\zeta\frac{\partial}{\partial\eta_0}+\eta_0\frac{\partial}{\partial\zeta}\right), \quad x_i=ia\left(\zeta\frac{\partial}{\partial\eta_i}-\eta_i\frac{\partial}{\partial\zeta}\right),\end{aligned} \tag{6}$$

and

$$\xi=ia\left(-\zeta\frac{\partial}{\partial\eta}+\eta\frac{\partial}{\partial\zeta}\right).$$

For this solution the eigenvalues of the space coordinates are discrete.

Returning to the general case, we should add Eq. (1) to the general Eqs. (4) and (5).

If we put $R=\infty$ we would get the special solution (2).

[1] H. Snyder, Phys. Rev. 71, 38 (1947).