compound nucleus, it is possible to compare the increase in level density with excitation energy with Weisskopf's level density function $\omega = C\exp(aE)^{\frac{1}{2}}$. a can be evaluated from these experiments:

$$a = 4(\epsilon_{max} - \epsilon)/T^2,$$

where $(\epsilon_{max} - \epsilon)$ is the excitation energy at which T is computed. Figure 16 shows the values for a_{exp} obtained from these experiments as compared to a_{theo} as evaluated by Weisskopf.[14] It is apparent that all the values for a_{exp} are considerably larger than a_{theo}. This would mean a very rapid increase in level density with increasing excitation energy; or, for the right level spacing at the neutron dissociation energy of a particular nucleus the level spacing at the ground state would be very much too large. It is possible that additional terms for the dependence of T on the excitation energy are necessary to account for the low lying levels which are not explainable by a statistical model. The experimental curves for ω show little tendency to be concave as would be expected from Weisskopf's density function. Otherwise, one might assume that high energy neutrons escape before the compound nucleus is formed. The number of neutrons necessary to account for the deviation from Weisskopf's function need only to be in the order of about 1 percent of the total number of neutrons emitted if their energy is larger than 6 Mev. These small effects are within the precision of our experiments.

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Proton Groups from the Deuteron Bombardment of F^{19} and P^{31}

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The $F^{19}(d, p)F^{20}$ and $P^{31}(d, p)P^{32}$ reactions were studied with 3.76-Mev cyclotron deuterons. The $F^{19}(d, p)F^{20}$ ground-state Q-value was found to be 4.16±0.08 Mev, giving 1.00211±0.00010 MU for the $F^{20}-F^{19}$ mass difference and 20.00660±0.00012 MU for the mass of F^{20}. Excited states of F^{20} were found at 0.64, 0.97, 1.31, 1.91, 2.52, 2.83, 3.45, and 4.01 Mev. The $P^{31}(d, p)P^{32}$ ground-state Q-value was found to be 5.52±0.10 Mev, giving 1.00065±0.00011 MU for the $P^{32}-P^{31}$ mass difference, and 30.98286±0.00021 MU for the mass of P^{31}. Excited states of P^{32} were found at 0.50, 1.10, 1.36, 1.71, 2.22, 2.72, and 3.27 Mev.

I. INTRODUCTION

A SURVEY of the light elements through oxygen indicates that, in general, the separation of the energy levels is 1 Mev or greater. Bower and Burcham,[1] studying the $F^{19}(d, p)F^{20}$ reaction with 800-kev deuterons showed that the F^{20} nucleus has four excited states under 2-Mev excitation. The present work was undertaken to determine whether the comparatively high density of levels exists in states of energy greater than 2 Mev. The reaction is also of interest in that a more accurate knowledge of the mass difference, $F^{20}-F^{19}$, is desirable.

TABLE I. Energy levels in F^{20}.

	Energy levels	Q	Q-values of Bower and Burcham
Q_0	0 Mev	4.16 Mev	4.3 Mev
Q_1	0.64±0.03	3.52	3.6
Q_2	0.97±0.05	3.19	3.3
Q_3	1.31±0.05	2.85	2.95
Q_4	1.91±0.04	2.25	2.4
Q_5	2.52±0.04	1.64	
Q_6	2.83±0.04	1.33	
Q_7	3.45±0.03	0.71	
Q_8	4.01±0.15	0.15	

The $P^{31}(d, p)P^{32}$ reaction was studied since very little has been done on the energy levels of P^{32}.

II. FLUORINE

Lead fluoride and beryllium fluoride targets of 1 to 2 mm air equivalent range were prepared by vacuum evaporation on thin gold foils. The targets were bombarded with deuterons of 3.76-Mev mean energy. The protons, emitted at 90° with the incident beam, were detected by a highly biased proportional counter. The proton ranges were determined by means of the interposition of aluminum foils and a variable pressure absorption cell. A composite curve of the proton groups observed with the lead fluoride targets is shown in Fig. 1. This curve has been resolved into nine groups, as indicated by the dotted lines.

Since the 24-cm and 34-cm groups corresponded to possible oxygen contaminants, further work was neces-

* Assisted by the Joint Program of the ONR and AEC.
[1] J. C. Bower and W. E. Burcham, Proc. Roy. Soc. (London) **173**, 379 (1939).

TABLE II. Energy levels of P^{32}.

	Energy levels	Q	Q-Pollard
Q_0	0 Mev	5.52 Mev	5.9±0.3 Mev
Q_1	0.50±0.05	5.02	
Q_2	1.10±0.03	4.42	
Q_3	1.36±0.05	4.16	
Q_4	1.71±0.04	3.81	
Q_5	2.22±0.04	3.30	
Q_6	2.72±0.03	2.82	
Q_7	3.27±0.04	2.25	

sary to justify their inclusion as fluorine groups. Pollard and Davison[2] have investigated the relative intensities of the two oxygen groups with a bombarding energy of 3.76 Mev and found them to be about equal. Therefore, because of the large yield of the 24-cm group relative to the 34-cm group, the shorter range group was attributed to fluorine. To check the 34-cm protons, it was decided to use a different fluorine compound in order to change the oxygen content. Beryllium fluoride was chosen, since studies of beryllium[3,4] indicated that no proton group would mask the 34-cm group in question. In the beryllium fluoride runs, the 34-cm group appeared with the same yield relative to the other fluorine groups, and thus it was ascribed to fluorine.

Table I lists the results as calculated from the proton yield curve. Corrections have been applied for range and

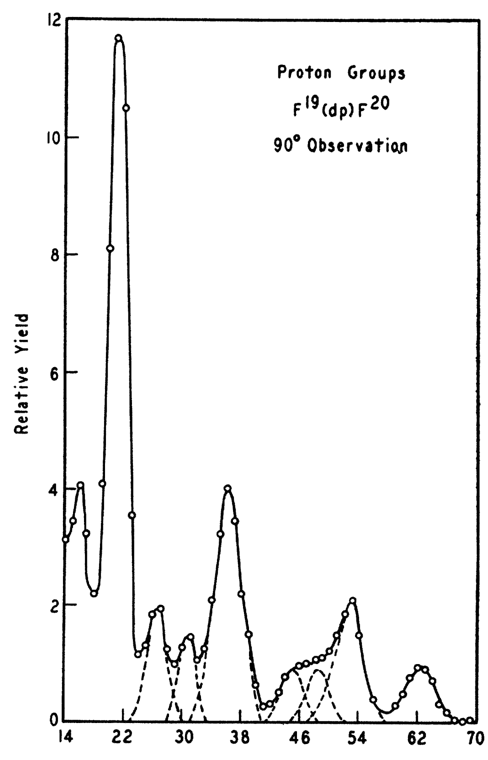

FIG. 1. Proton yield *versus* proton range.

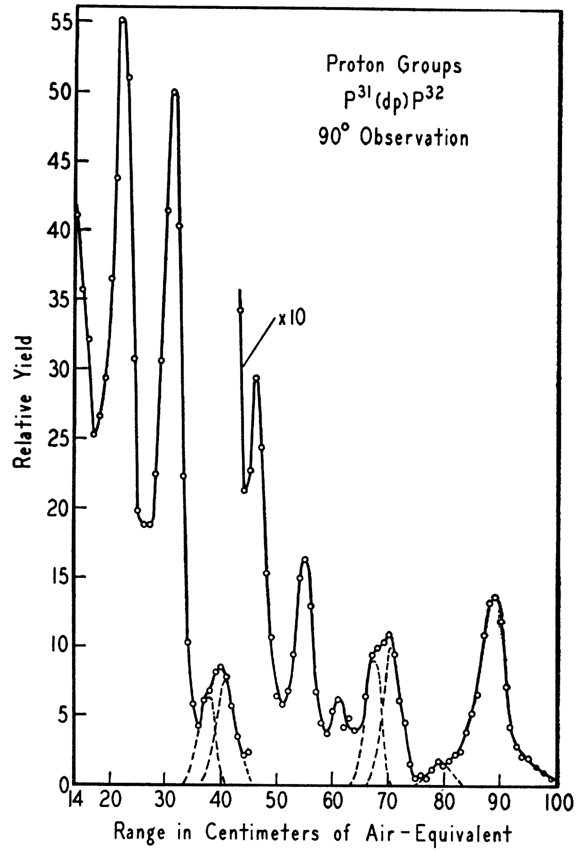

FIG. 2. Proton yield *versus* proton range.

angle straggling, beam inhomogeneity, and counter bias.[5,6] The errors quoted in Table I are relative errors and are stated with the energy levels. An additional error of ±0.05 Mev must be assigned to the absolute Q-values. The Q-values found by Bower and Burcham are also listed.

III. PHOSPHORUS

For the phosphorus reaction, the targets used were vacuum evaporated, 1 to 2 mm air equivalent, red phosphorus. The methods of detection and range measurement of the protons were the same as those used for fluorine.

In the case of phosphorus it was easier to rule out groups from contaminants because of the larger mass differences between phosphorus and the standard high yield, light element impurities. The group structure was observed at 90° and 0° with respect to the incident beam, so that from energy and momentum considerations, the shifts in the range of the groups for the two observations could be used to determine the approximate masses of nuclei giving rise to the groups.

Figure 2 shows the results for 90° observation. By the

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[3] E. Pollard, Phys. Rev. **57**, 241 (1940).
[4] W. W. Buechner and E. N. Strait, Phys. Rev. **76**, 1547 (1949).
[5] M. S. Livingston and H. A. Bethe, Rev. Modern Phys. **9**, 245 (1937).
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shift in range at 0° observation, the 24-cm and 34-cm groups were determined to be oxygen. The protons having an extrapolated range of 40 cm were found to be due to a carbon impurity. The remaining groups were assigned to phosphorus since their shifts at 0° were consistent with a mass of 32 for the residual nucleus.

Table II lists an analysis of the data. The analysis was made using the same corrections mentioned above. Again, an additional error of ±0.05 Mev should be assigned to the absolute Q values. Also listed is the ground-state Q value found by Pollard.[7]

IV. DISCUSSION

Using the mass values of Tollestrup, Fowler, and Lauritsen,[8] and the ground-state Q-value of 4.16 Mev the $F^{20}-F^{19}$ mass difference is calculated to be 1.00211 ±0.00010 MU. The mass of F^{20} is 20.00660±0.00012 MU. With a Ne^{20} mass[9] of 19.99890, the $Ne^{20}-F^{20}$ mass difference is −0.00770±0.00015 MU. This agrees well with the $F^{20}\rightarrow Ne^{20}+\beta^{-}$-decay scheme (−0.00784) found by many authors.[1,10,11] The agreement is not good, however, with the recent work of Jelley,[12] in which he finds the $Ne^{20}-F^{20}$ mass difference to be −0.00716 MU.

With the ground state Q-value of 5.52 Mev, the $P^{32}-P^{31}$ mass difference is determined to be 1.00065 ±0.00011 MU. Using the Mattauch and Flammersfeld[9] P^{32} mass, the P^{31} mass is 30.98286±0.00021.

The reactions[13–15]

$$Cl^{35}(d,\alpha)S^{33}\quad Q_0=9.1\text{ Mev}$$
$$S^{33}(d,p)S^{34}\quad Q_0=8.7\text{ Mev}$$
$$P^{31}(\alpha,p)S^{34}\quad Q_0=1.3\text{ Mev}$$

give the $Cl^{35}-P^{31}$ mass difference as 3.99609. The Cl^{35} mass[16] of 34.97903 leads to a P^{31} mass of 30.9829, in excellent agreement with the above value.

With the Mattauch and Flammersfeld aluminum and silicon mass values, the reactions[17,18]

$$Al^{27}(\alpha,n)P^{30}\quad Q_0=-2.93\text{ Mev}$$
$$P^{31}(\gamma,n)P^{30}\quad Q_0=-12.4\text{ Mev}$$

give a P^{31} mass of 30.98448 and[17,19]

$$Si^{30}(d,n)P^{31}\quad Q_0=4.56\text{ Mev}$$
$$Si^{28}(\alpha,p)P^{31}\quad Q_0=-2.23\text{ Mev}$$

give 30.98392 and 30.98361, respectively. These values do not agree with the present work.

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A Note Concerning the $C^{14}-N^{14}$ β-Decay

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The possibility that the parities of the ground states of C^{14} and N^{14} are opposite is discussed. Experiments which would determine or assist in determining the parity change are suggested.

The spins of C^{14} and N^{14} are known to be 0 and 1, respectively. The shell model predicts that C^{14} and N^{14} both have even parity. However, the $C^{14}-N^{14}$ beta-decay is forbidden. The value of ft is 8×10^{8}, implying a second-forbidden transition or possibly a highly unfavored first-forbidden transition, but certainly not an allowed transition. Nonetheless, it has been argued that the $C^{14}-N^{14}$ transition does not disagree with the shell model predictions.[1] The large ft value is explained on the hypothesis that the ground state of N^{14} is almost entirely $^3D_1$.

The ft value normally to be expected in this transition is about 6×10^{3}. This is the value of ft in the N^{13} and O^{15} decays, both of which are favored in Wigner's sense, as is $C^{14}-N^{14}$ in Wigner's theory.[2] To account for the observed ft-value of C^{14} on the above hypothesis, it is therefore necessary to assume that $[c(^3S_1)]^2$ is not more than about 10^{-5}, $c(^3S_1)$ being the coefficient of the normalized $^3S_1$ wave function in the ground states of N^{14}. Simultaneously, $[c(^5D_0)]^2$ in C^{14} must be approximately 10^{-5}, since $^5D_0$ to $^3D_1$ transitions are allowed. Moreover, the transition from O^{14} to the ground state of N^{14} is also forbidden, with a ft-value which is at least 2.4×10^{6} from the observations[3] that transitions to the ground state of N^{14} have a probability less than five percent of that for transitions to the excited level in N^{14}. It follows that $[c(^5D_0)]^2$ in O^{14} also is small if O^{14},

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