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NEON 18

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ABSTRACT

A new radioactivity which we assign to the nucleus Ne^{18} has been investigated. The decay is by the emission of positrons with an upper limit of 3.2 ± 0.2 Mev and a half life of 1.6 seconds. The spectrum of β rays was compared directly in a magnetic spectrograph with the known radiation of He^{6}. The β ray energy and decay rate correspond to a log F+ value of 2.9 ± 0.2, placing the activity in the superallowed class.

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INTRODUCTION

Studies of the mirror nuclei and of the isobaric triads have contributed greatly to the understanding of nuclear forces, and to the clarificaton of the theory of beta decay. Until the finding of Ne^{18}, which is described in this paper, only six sets of isobaric triads were known. These are $(Li\text{-}Be\text{-}B)^8$[1], $(Be\text{-}B\text{-}C)^{10}$[2], $(B\text{-}C\text{-}N)^{12}$[3], $(C\text{-}N\text{-}O)^{14}$[2], $(F\text{-}Ne\text{-}Na)^{20}$[1] and $(Na\text{-}Mg\text{-}Al)^{24}$[4]. Be^6 is certainly proton unstable, and F^{16} has been shown to be proton unstable.[1] Both of these instabilities are predicted on the simple assumption of charge symmetry of nuclear forces plus the calculated Coulomb energy differences of the extreme members of the triads, plus the known masses of He^6 and N^{16}. According to the same consideratons, Ne^{18} should be radioactive with a period of several seconds, and emit positrons with an upper limit of about 3.3 Mev.

Since one can presumably predict the properties of Ne^{18} with some confidence, it would appear at first sight that Ne^{18} should be very easy to find in the laboratory. Actually, it has turned out to be very difficult to observe Ne^{18} in the omnipresent background of Ne^{19} and N^{16}. These two activities are made whenever fluorine is bomarded with protons energetic enough to produce the reaction F^{19} (p, 2n)Ne^{18}. They both have very short periods, but unfortunately the period of Ne^{18} is shorter than that of either of the impurities, so there is no known way to separate the wanted activity from the unwanted. Several attempts were made to observe the growth of F^{18} from an unobservable Ne^{18}, mixed with Ne^{19}. This is the method of the "rayless transition," which was used by Rutherford in the early days of radioactivity. Liquid C_7F_{16} was bombarded with protons, and a stream of He gas carried Ne^{19} through active charcoal at liquid-air temperature into a large glass bottle containing a thin-walled Geiger counter. Neon, helium and hydrogen are the only gases that can pass through cold charcoal, and a pure 18.5-second period (Ne^{19}) of high intensity was observed in the bottle. It was hoped that by observing the activity of the F^{18} daughter as a function of the delay time in filling the bottle the lifetime of Ne^{18} could be measured. These experiments were unsuccessful. This proved to be due to a long "hold-up" time associated with the passage of neon gas through the charcoal trap. Although the volume of the trap was quite small, delay times for Ne^{19} as long as 40 seconds were measured. Ne^{18} was finally found by the use of a beta-ray spectrograph. This was possible because its end point is slightly higher than that of Ne^{19}, and the positrons from the decay of N^{16} to the "pair state" in O^{16} contribute a very small background.

EXPERIMENTAL TECHNIQUES

After some preliminary experiments with a very crude beta-ray spectrograph, which had indicated the presence of a short-lived Ne^{18}, we were able to use a much finer instrument, through the courtesy of Dr. Roger Wallace. His 180° magnetic spectrograph is patterned after that of Lawson and Tyler[5] and uses two proportional counters in coincidence as the detecting device. With this instrument, it was possible to separate completely the radiations of the 18.5-second Ne^{19} from those of the new shorter period, on the basis of beta-ray energy.

The short-period activity was induced by proton bombardment of targets of teflon $(CF_2)_N$ and a clear crystal of LiF. The target was bombarded by protons from the linear accelerator, and it was permanently fixed in the "source position" of the spectrograph (Fig. 1). Intensity measurements of the positron spectrum were made while the beam was turned off, after short bombardments of the target. The beam was monitored by a novel scheme due to Dr. W. K. H. Panofsky. The Faraday cup, which caught the beam after it passed through the target, was connected to a parallel RC network with a time constant equal to the mean life of the radioactivity. A fast recording electrometer gave a record of the voltage across the RC circuit. The reading of the electrometer at the instant the beam is turned off is obviously proportional to the activity of the target. The advantage of this system is that variations of the beam intensity during the bombardment do not affect the proportionality of integrator reading and source activity.

The beta spectrum could be investigated only above the end point of the strong Ne^{19} activity at 2 Mev. The shape of the spectrum between 2 Mev and 3.3 Mev was not appreciably affected by the LiF target thickness of 1.5 mm. LiF was very convenient to use since it yields the well known 0.85-second period of He^6, by the Li^7 (p, 2p)He^6 reaction. Its half-life and its upper limit of 3.50 Mev are very close to the corresponding properties of Ne^{18}, so no absolute calibration of the spectrograph was necessary. To observe He^6, one had merely to reverse the magnet current and change the time constant of the integrator circuit.

The output pulses of the spectrometer counters were fed to pulse shapers and to a conventional coincidence circuit. The coincident pulses were fed to a scaler with adjustable scaling factor, and the scaled output pulses were recorded on a Brush tape recorder. In order to prevent variations in the time after bombardment at which counting began, the pulses to the Brush tape recorder passed through a relay. The relay closed when the flip gates which served to interrupt the beam were in place. This arrangement gave a highly reproducible counting cycle.

The procedure for taking the data was to set the spectrometer magnet current to a desired value, open the flip gate for the desired length of bombardment, close the gate, and allow the decay to be recorded for long enough to establish a good background value. Enough runs were made in this manner at each value of the magnet current to give adequate statistical accuracy. The reading of the recording electrometer at the end of the bombardment was associated with each tape record of a decay.

The data were analyzed by adding all the runs at a given magnet current and plotting the resultant data as a function of time. The background was subtracted to get the net counts of the desired activity in the first second after bombardment. This number was divided by the total of the individual electrometer readings to give a normalized "count in first second" for each value of magnet current.

The data so obtained for He^6 were arranged in the form of a Fermi plot against an energy scale calculated from the magnet current and adjusted to give the tabulated end point of 3.50 Mev. The data for the 1.6-sec positron activity were plotted on the same scale (Fig. 2). The best fit by eye for these data yields an end point of 3.2 Mev.

A decay curve taken at the magnet current that gave the best ratio of 1.6-sec activity to background is shown in Fig. 3. From this we assign a value of the half-life of 1.6 ± 0.2 sec.

NUCLEAR ASSIGNMENTS

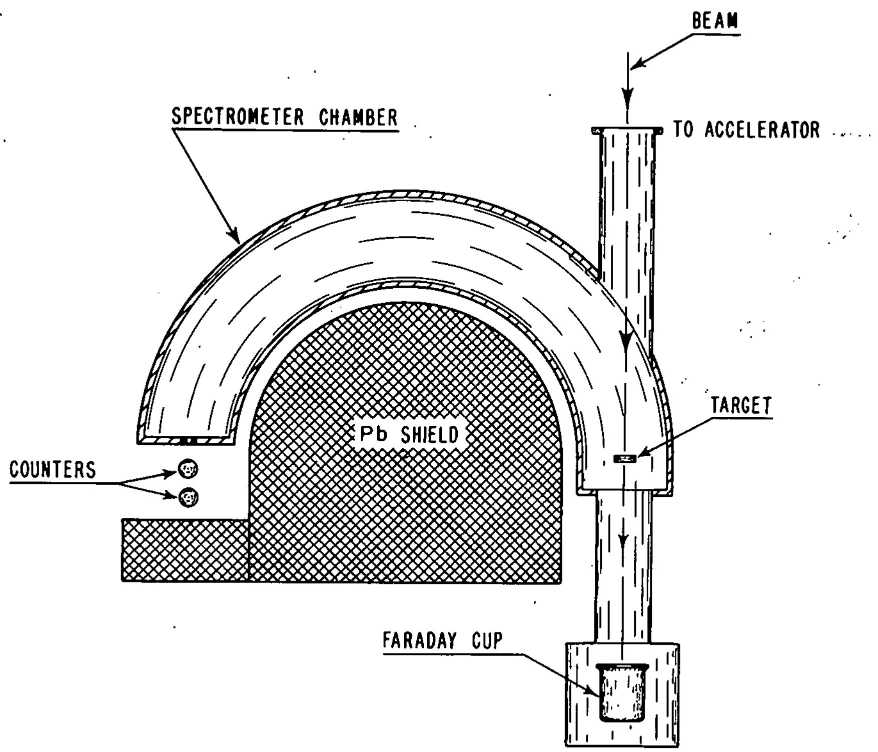
The activity was shown to be characteristic of fluorine by its appearance in proton-bombarded targets of LiF and CF_2, and its absence in targets of CH_2. Ne^{20*}, which is the compound nucleus formed in the reaction $F^{19} + p$, cannot decay by nucleon emission to any nucleus having either N or Z higher than 10. Since the resultant nucleus which we have investigated is positron-active, it lies on the neutron-deficient side of the stability line. The only presently unknown nuclear species which could be produced by 30-Mev protons on fluorine are Ne^{18}, Ne^{17} and F^{16}. Since F^{16} is known to unstable[(1)], the activity must be either Ne^{18} or Ne^{17}. If one assumes the activity to be Ne^{17}, the beta-ray energy, coupled with the known mass of F^{17}, gives a minimum possible mass for Ne^{17}. From this value, and the known masses of the other particles involved, one can calculate the threshold energy for the reaction F^{19} (p, 3n) Ne^{17}. The threshold would be 25.5 Mev. Although the backgrounds and low counting rates prevented the establishment, with high precision, of the threshold for producing the Ne^{18} activity, the activity was solidly in evidence when the incident proton energy was reduced to 22 Mev. Since this energy is below the minimum possible energetic threshold for producing N^{17}, we can eliminate that possibility. Even in the absence of this convincing evidence, one could feel sure that Ne^{17} would have much more energetic positrons (its triad counterpart is N^{17}), and would assign the new activity to Ne^{18} on the grounds that it behaves just as the theory would predict that it should.

CONCLUSION

Our value of 3.2 Mev for the upper limit of the beta-ray spectrum, coupled with the lifetime of 1.6 sec, gives a log ft value for the decay of Ne^{18} of 2.9 ± 0.1. This value clearly places the decay character in the same class as the other known A = 4n + 2 nuclei. The only other known nucleus with such a highly allowed beta decay is He^{6}, which has a log ft value of 2.95. The close agreement between the calculated mass of Ne^{18} and the observed upper limit of the protons indicates strongly that the transition goes to the ground state of F^{18}.

ACKNOWLEDGMENTS

We would like to express our appreciation to Dr. Roger Wallace for much valuable assistance, and to Dr. Sumner Kitchen, who also assisted in the experimental program. Our thanks also go to the members of the linear accelerator operating group who aided the experiment in many ways. This work was performed under the auspices of the Atomic Energy Commission.



SCHEMATIC EXPERIMENTAL SET UP.

Fig. 1

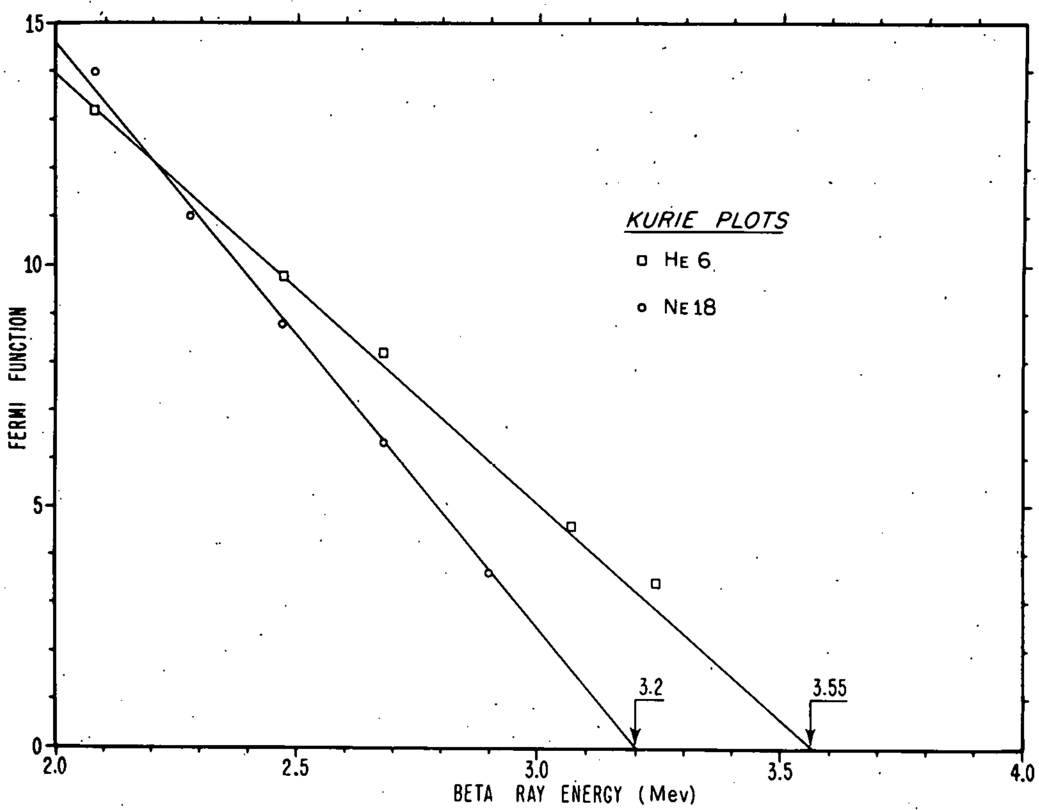
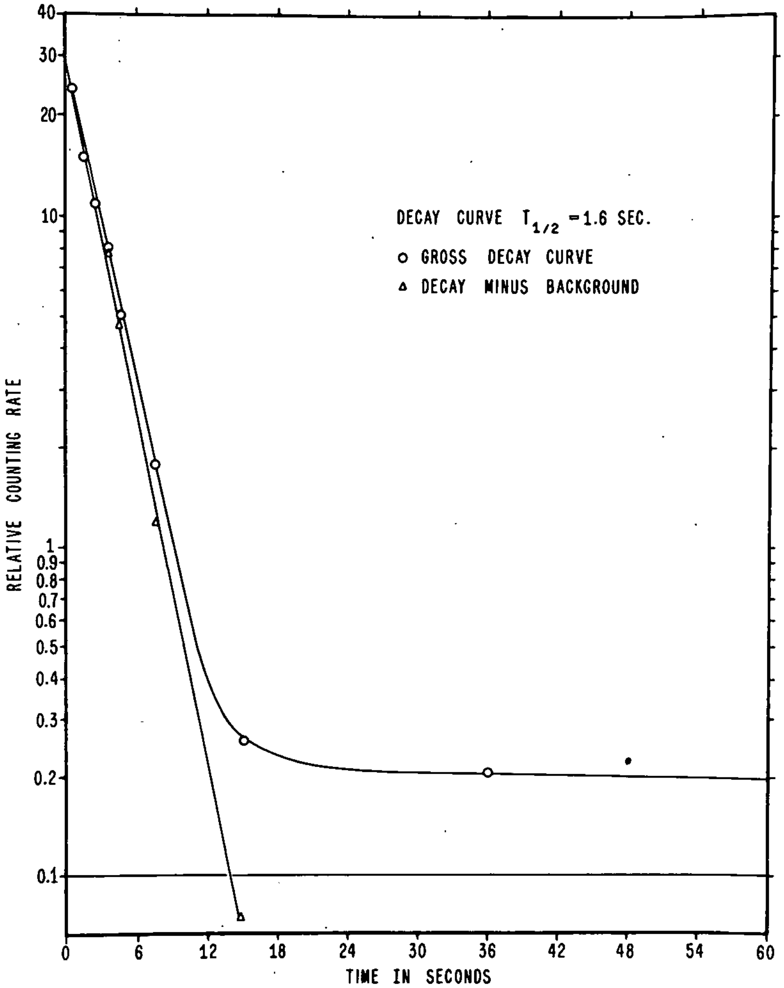

KURIE PLOTS
He 6
Ne 18
FERMI FUNCTION
BETA RAY ENERGY (Mev)
15
10
5
0
2.0
2.5
3.0
3.5
4.0
3.2
3.55

Fig. 2



DECAY CURVE $T_{1/2}$ = 1.6 SEC.
○ GROSS DECAY CURVE
△ DECAY MINUS BACKGROUND
RELATIVE COUNTING RATE
40
30
20
10
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
6
12
18
24
30
36
42
48
54
60
TIME IN SECONDS

Fig. 3

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