these conditions reduce to (15) and

$$\int [\phi, h'] d\mathbf{x}' = 0. \tag{27}$$

This last equation immediately gives the χ-equation:

$$\chi \equiv \pi^s{}_{,s} = 0. \tag{28}$$

We must remember that the h in (15) is now given by (25). Therefore the expressions that are given by (17), and which we shall now denote by $\chi_1{}^\sigma$, do not vanish weakly. Instead we obtain the χ-equations:

$$\begin{aligned}\chi^\sigma \equiv \chi_1{}^\sigma &+ (16\kappa)^{-1}(g^{44})^{-1}(-g)^{-\frac{1}{2}} g^{\sigma 4} g_{mn} \pi^m \pi^n \\ &+ \tfrac{1}{2}(g^{44})^{-1}(g^{\sigma 4} g^{n4} - g^{\sigma n} g^{44}) F_{mn} \pi^m \\ &- \kappa (g^{44})^{-1}(-g)^{\frac{1}{2}} g^{\sigma 4}\{g^{\mu\nu} g^{rs} g^{44} - g^{\mu r} g^{\nu s} g^{44} \\ &+ 2 g^{\mu 4} g^{\nu s} g^{r4} - g^{\mu\nu} g^{r4} g^{s4} - g^{\mu 4} g^{\nu 4} g^{rs}\} A_{\mu,s} A_{\nu,r} = 0.\end{aligned} \tag{29}$$

According to the general theory of [AB] there should be no other χ-equations.

PHYSICAL REVIEW VOLUME 87, NUMBER 3 AUGUST 1, 1952

The Disintegration of Cs^{130} †

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(Received April 16, 1952)

The disintegration of Cs^{130} (30 min) has been studied with the help of a magnetic lens spectrometer and a NaI(Tl) scintillation spectrometer. Cs^{130} decays to both Xe^{130} by positron emission and K electron capture and to Ba^{130} by negatron emission. The end-point energy of the positrons is 1.97 Mev and of the negatrons 0.442 Mev. Since no gamma-rays other than annihilation radiation were observed, it is assumed that the disintegration leads to the ground state of both Xe^{130} and Ba^{130}.

I. INTRODUCTION

THE disintegration of Cs^{130} was studied with a view of getting some additional information on the energy levels of Xe^{130}. Information exists[1] on the levels of Xe^{126}, Xe^{128}, and Xe^{130} which has been obtained from the study of the decay by beta-ray emission of the appropriate iodine isotopes. The spectrum accompanying the disintegration of I^{130} was investigated by Roberts, Elliott, Downing, Peacock, and Deutsch[2] from which the energy levels of Xe^{130} were obtained. The disintegration of I^{130} gives rise to gamma-rays of energy 0.417, 0.537, 0.667, and 0.744 Mev. The gamma-ray of energy 0.417 Mev was shown to arise from the two most highly excited levels of Xe^{130} but the remaining three gamma-rays are in cascade and, to date, it has not been determined which of these gamma-rays arises as a result of a transition from the first excited state to the ground state. The present work was an attempt to determine the energy of the first excited state of Xe^{130} from a study of the disintegration of Cs^{130} which decays, in part, by positron emission and orbital electron capture to Xe^{130}. This hope was not realized since, as we shall show, the disintegration of Cs^{130} does not lead to an excited state of Xe^{130}. However, the present work has shown that Cs^{130} decays to Xe^{130} by positron emission and orbital electron capture on the one hand and to Ba^{130} by electron emission on the other. In addition, certain conclusions concerning the configuration of Cs^{130} have been obtained.

Fink, Reynolds, and Templeton[3] produced a caesium activity, whose half-life is 30 min by the bombardment of I^{127} with alpha-particles. They reported that this activity emits x-rays and gamma-rays of about 0.5-Mev energy.

II. PREPARATION OF SOURCES

Resublimed elemental iodine, free of bromine and chlorine impurities, was used as the target for bombardments. The iodine was pressed into a copper target, which was water-cooled, and covered by a palladium foil 0.0005 in. thick and was bombarded by the 23-Mev alpha-particle beam of the Indiana University cyclotron. This thickness of palladium was calculated to be such as to slow down the high energy alpha-particles in the cyclotron beam to an energy for which the α-$2n$ reaction should be very improbable. The targets were bombarded at low beam intensity to keep the iodine from overheating.

The active caesium was separated in the following manner. The iodine was washed off the target with CCl_4, and the caesium and any other soluble salts were separated by extracting with a small amount of 1 normal HCl to which a small amount of caesium and heavy metal carrier had been added. Since some cadmium and silver activities can be produced in the palladium cover and can be driven into the iodine target, cadmium was used as the heavy metal carrier. The

† Supported by the joint program of the ONR and AEC.
[1] A. C. G. Mitchell, Revs. Modern Phys. **22**, 36 (1950).
[2] Roberts, Elliott, Downing, Peacock, and Deutsch, Phys. Rev. **64**, 268 (1943).
[3] Fink, Reynolds, and Templeton, Phys. Rev. **77**, 614 (1950).

active heavy metal was then removed by a hydrogen sulfide precipitation. The solution was filtered and evaporated. The evaporated portion contained the caesium activity from which sources were prepared.

The period of the resulting activity was measured repeatedly and was found to be 30 ± 1 min. There was no long-lived activity of any appreciable magnitude thus showing that Cs^{129} (31 hr) from an α-$2n$ reaction was not produced in the process. Incidentally, since no Cs^{129} is formed from an α-$2n$ reaction, it is clear that no Cs^{128}, whose half-life is reputed to be approximately 30 min,[3] could have been formed from an α-$3n$ reaction.

III. THE BETA-RAY SPECTRUM

The beta-ray spectrum was investigated with the help of a magnetic lens spectrometer. In the first series of experiments the lens was not equipped with any device to separate electrons from positrons. The counter was supplied with a thin Zapon window which would transmit positrons or electrons of energy 15 kev or greater. The sources were quite thin, being essentially carrier free, and were deposited on thin Zapon.

Owing to the short half-life of Cs^{130}, it was found to be impossible to go over the whole range of the particle spectrum with one source. Sources from several different bombardments were used and separate regions of the spectrum were investigated with each source. There was enough overlap between the regions investigated so that it was possible to form a composite diagram covering the whole extent of the spectrum.

A Fermi analysis of the data was made and the results are shown in Fig. 1. It will be seen that there is a high energy group of positrons, the energy of whose end point is 1.97 Mev. In addition there is a low energy group of particles causing a bending away from the high energy positron group at about 0.44 Mev. If a Fermi plot is made of this low energy group, using values of $F(Z, W)$ appropriate to positrons, no reasonable straight line could be obtained. If functions appropriate to electrons were used, however, the straight line labeled e^- in Fig. 1 was obtained. The energy of the end point of the negatron group is 0.442 Mev.

In order to prove that the high energy group consists of positrons and the low energy group of negatrons, a spiral baffle was inserted in the lens. This cut down the intensity of the radiations reaching the counter to an considerable extent, but the experiments were good enough to confirm the fact that the high energy group consists of positrons and the low energy one of negatrons.

Finally an experiment was performed in which the counter was fitted with a thin Zapon window, supported on a grid, and capable of transmitting electrons of 5 kev or greater. These experiments showed the K-$2L$ Auger line of xenon appearing at 24 kev, showing that Cs^{130} decays to Xe^{130} by K electron capture. In addition, the experiments with the 5-kev window were carried far enough up on the continuous distribution so that

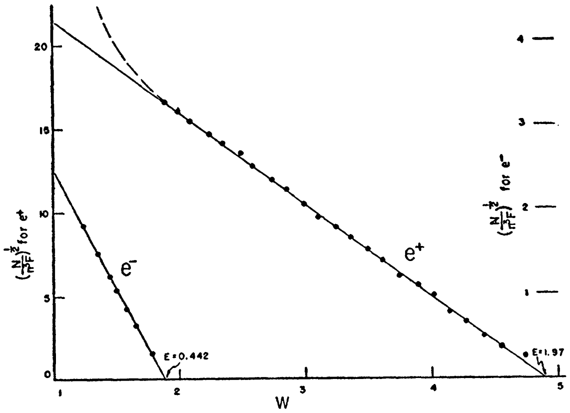

FIG. 1. Fermi plot of disintegration particles from Cs^{130}.

the whole spectrum could be plotted. The results are shown in Fig. 2.

The relative abundances of the positron and negatron groups, the values of logft, and the ratio of Auger electrons to positrons are shown in Table I. Owing to the short life of Cs^{130} the experiments are not suitable for determining the value of K/e^+.

IV. MEASUREMENT OF GAMMA-RAYS

The intensity of the sources was not strong enough to permit one to determine the energy of the gamma-rays in the magnetic lens spectrometer. The gamma-rays were therefore studied with the help of a scintillation counter. The apparatus consisted of a NaI(Tl) crystal, linear amplifier, and differential pulse-height discriminator. A typical experiment is shown in Fig. 3 in which the number of counts per minute corrected for decay is plotted against the discriminator setting. In these experiments the window opening of the discriminator was 1.5 volts. In order to calibrate the apparatus a similar curve to Fig. 3 was taken using the 0.663-Mev line of Cs^{137} with identical gain settings.

Referring to Fig. 3, the peak at discriminator setting 34 div. corresponds to a photoelectric peak for annihilation radiation. The peak at B comes at the place to be expected for the "backscattered peak" of the Compton effect for annihilation radiation. The arrows indicate the peaks to be expected for the gamma-rays of energies

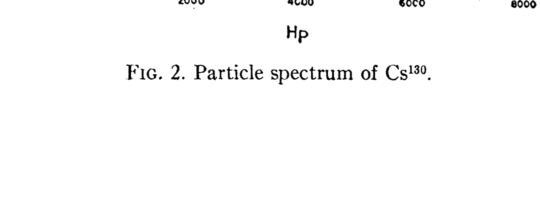

FIG. 2. Particle spectrum of Cs^{130}.

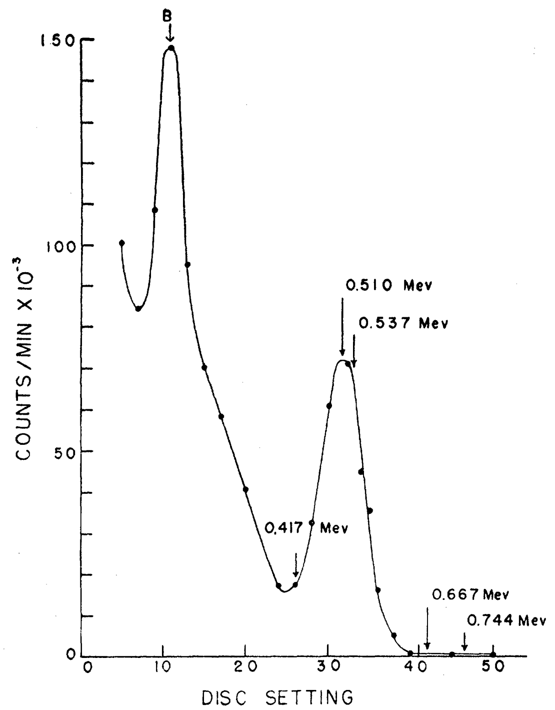

FIG. 3. Pulse-height distribution for gamma-rays from Cs^{130} using scintillation counter.

0.774, 0.667, 0.537, and 0.417 Mev reported from a measurement of the spectrum of I^{130} by Roberts *et al.* It will be seen that the lines at 0.667 and 0.744 Mev are not seen, their intensity being less than 3 percent of that of the annihilation radiation. The line at 0.537 Mev would not be resolved from the annihilation radiation and the line at 0.417 Mev would be seen if it had 10 percent of the intensity of that of the annihilation radiation.

In order to show that decay by K electron capture is taking place, the gain on the amplifier was changed and the low energy region was searched. A line was found corresponding to an x-ray of 29.5 kev, arising from the $K\alpha$ radiation of xenon.

V. DISCUSSION

The experiments have shown that Cs^{130} decays in two ways—(a) by positron emission and orbital electron capture to Xe^{130} and (b) by negatron emission to Ba^{130}. The lines at 0.744, 0.677, and 0.417 Mev seen in the corresponding decay of $I^{130} \rightarrow Xe^{130}$ are entirely absent, and it does not appear likely that the line at 0.537 Mev is excited either. It is, therefore, to be assumed that the decay of Cs^{130} to Xe^{130} goes to the ground state of the latter.

Aside from the failure to find gamma-rays there are convincing arguments in favor of this point of view. Cs^{130} goes to both Ba^{130} and Xe^{130} and both of these nuclei are even-even nuclei with, presumably, zero spin and even parity. Referring to Table I, it will be seen that both the negatron and positron transitions have a value of logft of 5, which corresponds to an allowed transition. This would indicate that the spin of the ground state of Cs^{130} is 1 and that it has even parity. The transitions to the higher excited states of Xe^{130}, while possible from energy considerations, are forbidden, presumably, on account of spin change.

It is interesting to compare the results of this experiment with predictions based on the shell model. Since ${}_{55}Cs^{130}$ has 55 protons, the shell model would predict that the proton configuration would be either $g_{7/2}$ or $d_{5/2}$. These two states have approximately the same energy. The configuration appropriate to 75 neutrons is $d_{3/2}$. Since Cs^{130} goes to the ground states of both Xe^{130} and Ba^{130} (spin 0, even parity) by means of allowed transitions, Cs^{130} probably has even parity and spin 1. The configuration $(d_{5/2}, d_{3/2})$ would give even parity and spin 1, in agreement with the results of this experiment. The other possible assignment, namely $(g_{7/2}, d_{3/2})$ would imply a spin of 2 which these experiments rule out.

In this connection it is instructive to compare the configurations corresponding to 55 protons for several caesium isotopes for which the spin has been measured

TABLE I. Characteristics of the decay of Cs^{130}.

	Energy Mev	Percent abundance	logft	Auger/positrons
$Cs^{130} \rightarrow Xe^{130}(e^+)$	1.97	96.5	5.08	4.5
$Cs^{130} \rightarrow Ba^{130}(\beta^-)$	0.442	3.5	4.96	···

or for which the configuration can be deduced from arguments similar to those given above. These configurations are as follows: $Cs_{75}{}^{130}(d_{5/2}-d_{3/2})$, $Cs_{76}{}^{131}(d_{5/2})$,[4] $Cs_{78}{}^{133}(g_{7/2}-)$,[5] $Cs_{80}{}^{135}(g_{7/2}-)$,[6] and $Cs_{82}{}^{137}(g_{7/2}-)$.[6] The first two are derived from measurements of logft and the last three from actual measurements of spin. The influence of the increase in neutrons seems to be that below neutron number $N=78$ the $d_{5/2}$ state for the fifty-fifth proton lies lower and from $N=78$ on the $g_{7/2}$ state lies lower.

The present experiments clearly allow one to compute the mass differences between the stable isobars Ba^{130} and Xe^{130}. Thus

$$Cs^{130}=Ba^{130}+0.442 \text{ Mev};$$
$$Cs^{130}=Xe^{130}+1.97+2m_0c^2;$$
$$\text{or } Ba^{130}=Xe^{130}+2.53 \text{ Mev } (2.72\times10^{-3} \text{ MU}).$$

The authors are indebted to Dr. M. B. Sampson and the cyclotron group for making the bombardments and to Mr. A. E. Lessor for carrying through the chemical separations.

[4] R. Canada and A. C. G. Mitchell, Phys. Rev. **83**, 76 (1951).
[5] See, for example, National Bureau of Standards, Circular No. 499 (1950).
[6] Davis, Nagle, and Zacharias, Phys. Rev. **76**, 1068 (1949).