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NUCLEAR SPIN OF ASTATINE-211†

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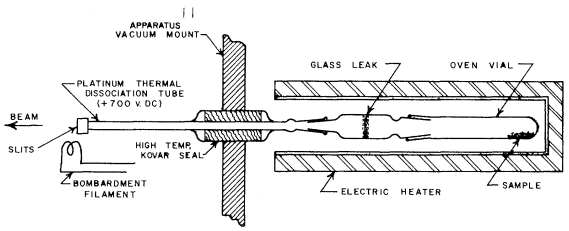
In 1940 Corson, Mackenzie, and Segrè isolated a radioactive element whose chemical, physical and nuclear properties established it to be element 85, the last of the halogen group.[1] This element, which does not possess a stable isotope, was named astatine.[2] This note reports a measurement of the nuclear spin of one of the astatine isotopes, the 7.2-hr At^{211}, by the method of atomic beams. This measurement constitutes the first direct spin determination of an isotope, having no stable counterpart, whose half-life is measured in hours. It is of interest to note that each run was made with approximately 10^{13} atoms of At^{211}. The At^{211} was produced by an $(\alpha, 2n)$ reaction on a bismuth target in the Berkeley 60 in. cyclotron. A bombarding energy of 29 Mev was employed to preferentially produce At^{211} free of At^{210}. The astatine was separated from the target by evaporation; the target was heated to 700°C in air and the astatine collected upon a platinum foil. In order to produce an atomic beam, it was found necessary to mix the astatine with a natural carrier, and iodine was chosen because of the similarity of its chemical properties to those of astatine. The platinum foil was placed in an evacuated flask with approximately 200 mg of iodine and heated to drive off the astatine. An intimate mixing of the astatine and iodine was ensured by distilling the mixture several times from one end of the vial to the other. The atomic beam of astatine was produced by thermal dissociation of the At-I complex in a platinum tube heated by electron bombardment to approximately 700°C (Fig. 1). The astatine-iodine mixture was introduced into the platinum tube through a slow leak. The oven vial and associated glassware were maintained at a temperature of approximately 100°C to prevent absorption of the active material in the glass. With this arrangement, a 70% to 80% dissociated beam of astatine atoms was obtained. The beam was collected upon buttons coated with evaporated silver and detected by counting the decay α particle in continuous-flow proportional counters.



ASTATINE BEAM SOURCE

FIG. 1. Astatine beam source.

The method used in this experiment is the atomic-beams "flop-in" technique due to Zacharias.[3] The apparatus used has been described elsewhere.[4]

In astatine the electronic configuration is $6p^5$ and Hund's rule predicts that the ground electronic state is $^2P_{3/2}$ With this configuration and a nuclear spin $I > 0$, there are, with normal ordering of the hyperfine levels, two observable "flop-in" transitions. These are

$$(F = I + \tfrac{3}{2},\ M_F = -I + \tfrac{1}{2}) \rightarrow (F = I + \tfrac{3}{2},\ M_F = -I - \tfrac{1}{2}),$$

and

$$(F = I + \tfrac{1}{2},\ M_F = -I + \tfrac{3}{2}) \rightarrow (F = I + \tfrac{1}{2},\ M_F = -I + \tfrac{1}{2}),$$

where F is the total angular-momentum quantum number of the atom, I the nuclear spin quantum number, and M_F the projection of F along the direction of quantization. If g_F is the g factor of the particular F level in which a transition is observed at frequency V_x in a magnetic field H, we have

$$V_x \approx g_F \frac{\mu_0 H}{h}, \qquad (1)$$

where μ_0 is the Bohr magneton and h is Planck's

constant. For a $^2P_{3/2}$ electronic state,

$$g_F \cong \frac{4}{2I+3} \quad (F = I+\tfrac{3}{2}),$$
$$g_F \approx \tfrac{4}{3}\,\frac{2I+9}{(2I+1)(2I+3)} \quad (F = I+\tfrac{1}{2}), \tag{2}$$

assuming pure Russel-Saunders coupling and vanishing nuclear magnetic moment. The magnetic field H is determined by observing a transition in an isotope of known spin. In this experiment a beam of Cs^{133} was employed. For Cs^{133}, I is $\frac{7}{2}$, $J = \frac{1}{2}$, and (at moderate fields) for the transition $(F = 4,\ M_F = -3) \rightarrow (F = 4,\ M_F = -4)$, we have, at a given field H,

$$V_x/V_{Cs} \cong 4g_F, \tag{3}$$

where V_{Cs} is the observed cesium frequency. In order to determine the nuclear spin of an isotope, it is only necessary to search for a signal due to the isotope of unknown spin at the discrete frequencies determined by (3).

In the case of At^{211}, both "flop-in" transitions have been observed at three different fields of 2.86, 5.71, and 8.56 gauss, corresponding to cesium resonance frequencies of 1, 2, and 3 Mc. Fig. 2 exhibits two resonances observed at a field of 8.56 gauss. The resonance (α) is the one observable "flop-in" resonance in the state $F = I + \frac{3}{2}$; (β) is the corresponding resonance in the state $F = I + \frac{1}{2}$. Despite the intimate mixing of iodine and astatine, the beam was not steady and varied irregularly with time. In order to compensate for this variation, the resonance button signals were normalized against the direct beam (i.e., the signal with the apparatus stop wire withdrawn), measured immediately before and after the resonance exposure. The ordinate in Fig. 2 is the resonance counting rate expressed as a percentage of the direct beam counting rate. All resonances observed are consistent with an assignment of $\frac{9}{2}$ for the nuclear spin of At^{211}. Positive identification of the isotope was made by decaying some of the resonance peak buttons. The decay half-life observed by us (7.2 hr) agrees well with that quoted in the literature.[5]

At^{211} contains a magic number of neutrons (N = 126) and the $h_{11/2}$ proton shell is closed at Z = 82. The observed spin of $\frac{9}{2}$ is simply understood on the basis of the single particle shell model by assigning the three odd protons to the $h_{9/2}$ level. Two of the protons pair, and the spin is determined by the last odd proton.

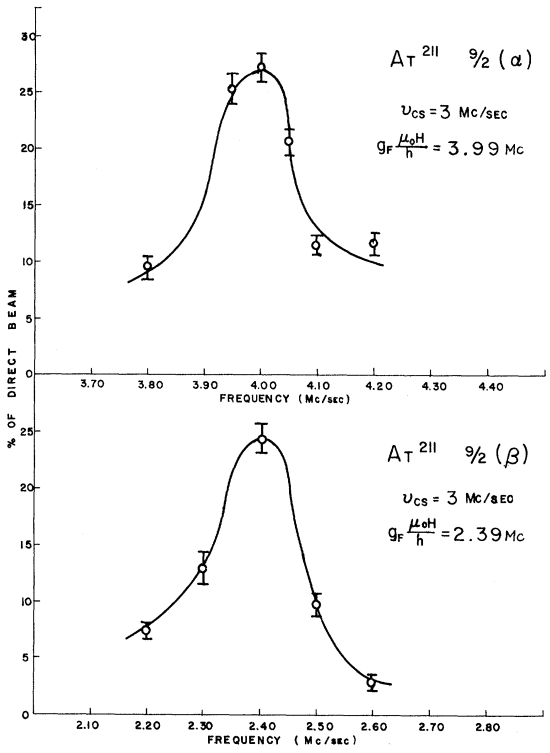


FIG. 2. Astatine resonances observed at a magnetic field of 8.56 gauss. Resonances have been normalized against the direct beam.

Measurements are in progress to determine the nuclear magnetic and electric quadrupole moments of At^{211}.

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