# The Disintegration of $As^{72}$*

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The spectra of the various radioactive arsenics produced by high energy alpha-particle bombardment of gallium have been studied using a magnetic lens spectrograph. These isotopes consist of $As^{72}$ (26 h), $As^{74}$ (19.5 d), $As^{73}$ (90 d) and $As^{71}$ (60 h). The main investigation concerns $As^{72}$. This element is found to emit five positron groups of end-point energies 3.339 (19.3 percent), 2.498 (64.6 percent), 1.844 (12.1 percent), 0.669 (5.0 percent) and 0.271 (2.0 percent) Mev. A strong gamma-ray of energy 0.835 Mev together with many weak gamma-rays with energies up to 3 Mev have been found. The levels of the product nucleus $Ge^{72}$ agree well with those found from a study of $Ga^{72}$. The highest energy positron group has a forbidden shape. The spectrum of $As^{74}$ consists of one gamma-ray of energy 0.593 Mev, two negatron groups of energies 1.45 and 0.82 Mev together with a positron group of energy about 0.96 Mev. $As^{73}$ disintegrates by $K$-electron capture and the emission of an internal conversion line corresponding to a gamma-ray of 0.052 Mev. An internal conversion line corresponding to a gamma-ray at 0.162 Mev is ascribed to $As^{71}$.

## I. INTRODUCTION

THE study of the spectrum of $As^{72}$ was undertaken in order to obtain more evidence about the various energy levels of $Ge^{72}$, since $As^{72}$ is a positron emitter which leads to $Ge^{72}$. The states of $Ge^{72}$ have been investigated by Mitchell, Zaffarano, and Kern[1] and by Haynes[2] through an investigation of the beta- and gamma-rays of $Ga^{72}$. The spectrum of $Ga^{72}$ turned out to be extremely complicated, consisting of seven beta-ray groups and some eight or nine gamma-rays, most of them weak. The two sets of independent investigators are in reasonable agreement on the level scheme determined from their data. About the only point of divergence is the question as to where to place an internally converted gamma-ray of 0.700 Mev energy. This line was originally discovered by Bowe, Goldhaber, Hill, Meyerhoff, and Sala[3] with the help of coincidence counting techniques. They showed that coincidences between disintegration electrons and the internal conversion electrons from the gamma-ray in question are delayed. They therefore assumed that the state giving rise to the internally converted gamma-ray was a metastable one of about 30 $\mu$sec. half-life and followed a weak beta-ray transition. Mitchell, Zaffarano, and Kern placed this transition rather high in the disintegration scheme and thought that they had found a gamma-ray in the photo-electron spectrum corresponding to the internally converted gamma-ray in question.

In order to obtain corroborative evidence on the levels of $Ge^{72}$, the investigation of $As^{72}$ was undertaken. In the process of producing $As^{72}$, the radioactive nuclei $As^{71}$, $As^{73}$, and $As^{74}$ were also produced and information concerning the spectra of these elements was also obtained.

$As^{72}$ was produced in the cyclotron by bombarding gallium with 23-Mev alpha-particles. Since gallium has two stable isotopes, $Ga^{69}$ and $Ga^{71}$, it is clear that $As^{72}$ (26 hours) and $As^{74}$ (17.5 days) will both be produced as a result of an $(\alpha,n)$ reaction. It was found also that $As^{71}$ and $As^{73}$ were formed by an $(\alpha,2n)$ reaction.

## II. PREPARATION OF THE SOURCES

In order to prepare the sources, $Ga_2O_3$ was pressed into grooves in the target plate of the cyclotron and bombarded with 23-Mev alpha-particles for a total irradiation of 80 to 125 microampere hours. The target material was placed in a distilling flask with 1 gram of hydrazine sulfate and 75 ml concentrated HCl, together with a small amount of arsenic carrier, and the $AsCl_3$ distilled over. The arsenic was finally precipitated with $H_2S$.

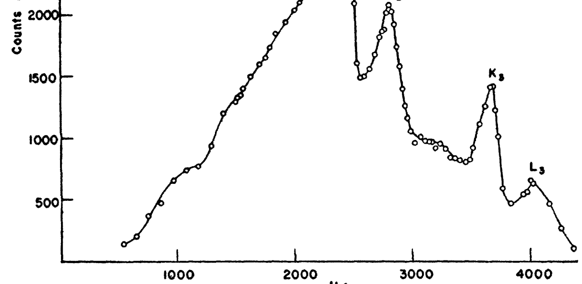


FIG. 1. Gamma-rays from $As^{72}$ and $As^{74}$; distribution of photo-electrons (U radiator).

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[1] Mitchell, Zaffarano, and Kern, Phys. Rev. 73, 1424 (1948).

[2] S. K. Haynes, Phys. Rev. 74, 423 (1948).

[3] Bowe, Goldhaber, Hill, Meyerhoff, and Sala, Phys. Rev. 73, 1219A (1948).

TABLE I. Energy levels of $Ge^{72}$ (Mev).

| Levels obtained from $Ga^{72}$ (MZK) | (H) | Levels obtained from $As^{72}$ Allowed Positron energy | Levels | Forbidden Positron energy | Levels |
|---|---|---|---|---|---|
| 0 | 0 | 3.386 | 0.0 | 3.339 | 0.0 |
| 0.835 | 0.84 | 2.486 | 0.900 | 2.498 | 0.841 |
| 1.47 | 1.47 | 1.849 | 1.537 | 1.844 | 1.495 |
| 2.16 | — | — | — | — | — |
| 2.52 | 2.52 | 0.669 | 2.717 | 0.669 | 2.67 |
| 3.02 | 3.05 | 0.255 | 3.131 | 0.271 | 3.07 |
| 3.34 | 3.35 | | — | — | — |

## III. THE SPECTRUM OF $As^{72}$

A preliminary investigation of $As^{72}$ by Mitchell, Jurney, and Ramsey,[4] using absorption and coincidence counting methods, indicated that the beta-ray end point was 2.78 Mev, that there was a gamma-ray of about 2.4 Mev, as determined by the coincidence absorption of Compton electrons, and that the spectrum was complex.

In the present investigation, the gamma-ray spectrum was determined by measuring the distribution of photo-electrons ejected from a uranium or lead radiator, in a magnetic lens spectrograph. The uranium radiator had a surface density of 90 mg/cm$^2$. Various lead radiators were used having surface densities from 15 to 77 mg/cm$^2$. The result of a typical experiment, using a uranium radiator, is shown in Fig. 1. Only that portion of the curve below about 1 Mev is shown. Beyond 1 Mev the gamma-ray intensity is quite weak and it is practically impossible to find lines with any certainty. The highest energy gamma-ray appears to be around 3 Mev. In Fig. 1 the following lines are to be seen: $K_1$, the $K$ photo-line for annihilation radiation; $K_2$, the $K$ photo-line for a gamma-ray of energy 0.593 Mev, coming from $As^{74}$; $K_3$, $L_3$, the $K$ and $L$ lines for a gamma-ray of energy 0.835 Mev from $As^{72}$. By observing the decay of the spectrum it was shown that all of the radiation of energy greater than 1 Mev comes from $As^{72}$.

The line at 0.835 Mev is the strongest line in the $As^{72}$ spectrum and is also the strongest line in the spectrum of $Ga^{72}$. There is some evidence for a line at 1.05 Mev, obtained with a lead radiator, which was also observed in the spectrum of $Ga^{72}$. A careful search was made for a line at 0.637 Mev, observed as a strong line in $Ga^{72}$, but this was not observed in any intensity. It is apparent, from studying the data, that the many weak lines of high energy, seen in $Ga^{72}$, are making a contribution to the high energy part of the spectrum of $As^{72}$. However, the relative intensity of these lines, compared to the line at 0.835 Mev, appears to be considerably less than in $Ga^{72}$.

The beta-ray spectrum of the arsenic produced from the irradiation of gallium was next investigated. It was found that if the full energy of the beam of 23-Mev alpha-particles was used to produce the source, certain internal conversion lines owing to $As^{71}$ and $As^{73}$ appear. If, however, the energy of the beam was limited to 12 to 13 Mev by placing thin aluminum sheets in front of the target, the extraneous lines disappeared. Figure 2 shows the spectrum of the beta-rays from arsenic under conditions in which the lines from $As^{71}$ and $As^{73}$ do not appear. The spectrum consists of radiations from $As^{72}$ and $As^{74}$. One feature to be noted in the spectrum is the

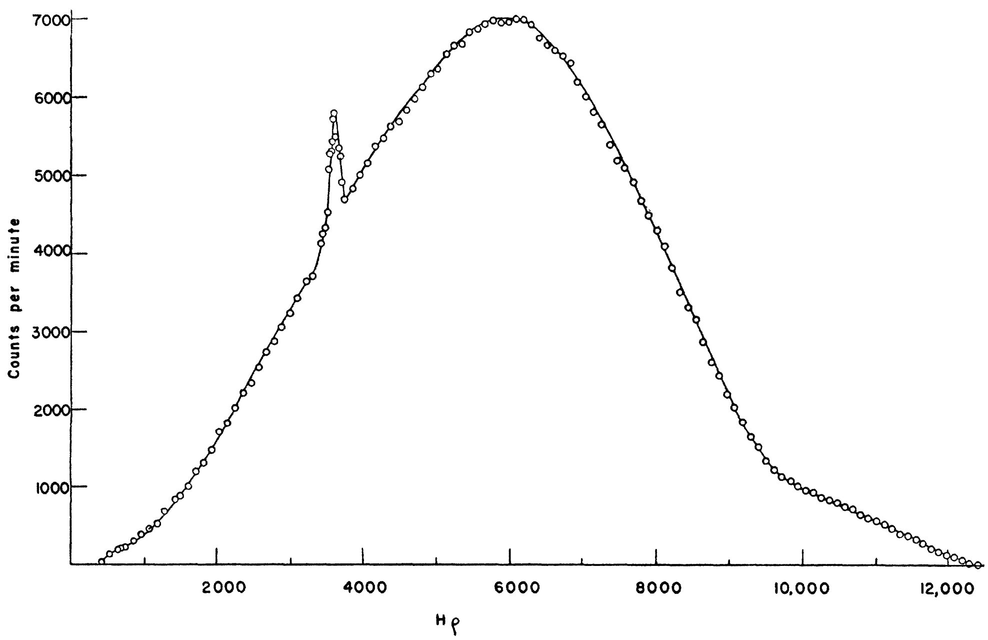


FIG. 2. Beta-ray spectrum of $As^{72}$.

[4] Mitchell, Jurney, and Ramsey, Phys. Rev. 71, 825 (1947).

internal conversion line at 3631 gauss-cm—corresponding to a gamma-ray energy of $0.700 \pm 0.003$ Mev.

In order to analyze this spectrum, the $As^{72}$ (26 hours) was allowed to decay completely and measurements were made on the remaining $As^{74}$ (17.5 days). The original data were then corrected for the presence of $As^{74}$. Since the end-point energy of $As^{74}$ is approximately 1.45 Mev, no corrections were necessary at energies higher than this.

After the corrections mentioned were made to the data, the beta-ray distribution was analyzed by the usual method of Fermi-plots. In the first analysis it was assumed that all of the spectra involved have an allowed shape. Under this assumption it was found that the spectrum could be resolved into five groups having the end point energies shown in column 3 of Table I. Table I also shows the energy levels of $Ge^{72}$, obtained from a study of $Ga^{72}$ by Mitchell, Zaffarano, and Kern (MZK) and Haynes (H). It will be seen at once that, while the difference in energies of the two highest energy beta-ray groups is of the right order of magnitude to account for the gamma-ray at 0.835 Mev, the fit is not good enough and as a result the levels of $Ge^{72}$, determined in this manner, are raised above the levels as determined from $Ga^{72}$.

An inspection of the Fermi plot of the high energy group revealed that it has a slight curvature, concave toward the energy axis. Such a behavior suggests that the transition is forbidden. The most obvious shape factors to try for this type of behavior are (a) first forbidden $\Delta j = \pm 2$, change of parity and (b) second forbidden $\Delta j = \pm 3$, no change of parity. Both possibilities were tried with the result that the second forbidden shape did not fit the data whereas the shape corresponding to first forbidden, $\Delta j = \pm 2$, change of parity gave a very good fit. The analysis of the complete spectrum was then carried out under the assumption that the high energy group has the forbidden shape given under assumption (a) above. The results are shown in the last two columns of Table I. It will be seen that the difference in energy of the two most energetic groups, 0.841 Mev, is in good agreement with the energy of the gamma-ray, 0.835 Mev, and furthermore that the levels of $Ge^{72}$, determined in this manner, show quite good agreement with those determined from $Ga^{72}$. The relative abundances and comparative half-lives of the group are given in Table II.

As has already been mentioned, the shape of the spectrum of the highest energy group implies that it belongs to the first forbidden class with $\Delta j = \pm 2$ and a change of parity. Shull and Feenberg[5] have collected information on some eleven disintegrations of this class. They point out that the quantity $(W_0^2 - 1)ft$ is approximately $10^{10}$ for all of these nuclei. For the highest energy group of $As^{72}$ the quantity $(W_0^2 - 1)ft = 1.1 \times 10^{10}$, which agrees with the classification of Shull and Feenberg.

[5] F. B. Shull and E. Feenberg, Phys. Rev. **75**, 1768 (1949).

TABLE II. Positron groups of $As^{72}$.

| End-point energy Mev | Relative abundance (percent) | Ft. (sec.) |
|---|---|---|
| 3.339 | 19.3 | $2.0 \times 10^8$ |
| 2.498 | 61.6 | $1.8 \times 10^7$ |
| 1.844 | 12.1 | $5.4 \times 10^6$ |
| 0.669 | 5.0 | $0.97 \times 10^6$ |
| 0.271 | 2.0 | $5 \times 10^4$ |

An attempt can be made to correlate these findings with predictions based on the nuclear shell model. The ground state of the product nucleus $_{32}Ge^{72}$ should have zero spin and even parity. The parent nucleus $_{33}As^{72}$ is a nucleus of the odd-odd type and it is therefore somewhat difficult to predict its configuration. According to Mayer[6] the odd proton should be in a $p_{3/2}$ state. This is in agreement with the fact that the spin of $_{33}As^{75}$ is 3/2. The next higher proton state would be $f_{5/2}$. The thirty-ninth neutron is expected to go into a $p_{1/2}$ state and the next higher state would be $g_{9/2}$. The shell model would predict a state $(p_{3/2}p_{1/2})$ for $As^{72}$. Now in order to account for the fact that the shape of the high energy spectrum is first forbidden, $\Delta j = \pm 2$ with a change of parity, it is necessary that the ground state of $As^{72}$ have odd parity with a spin of 2. This could be accounted for by the configuration $(f_{5/2}g_{9/2})$. The configuration $(p_{1/2}p_{3/2})$ would not be in agreement with the data since this state would have even parity and the transition would display a shape which would not fit the data.

The energy levels of $Ge^{72}$ as determined from the analysis of the beta-ray spectrum of $As^{72}$ are in quite good agreement with those determined from the spectrum of $Ga^{72}$. The experiments on $As^{72}$ definitely show that the first excited state of $Ge^{72}$ lies at 0.835 Mev above the ground state. This, of course, could only be inferred in the study of the spectrum of $Ga^{72}$. It remains to explain why the line at 0.835 Mev is so much more intense than all the other lines in the spectrum of $As^{72}$, while this is not the case in $Ga^{72}$. An inspection of Table II shows that 62 percent of all the beta-ray transitions lead to the 0.835-Mev level and only 18 percent to higher levels. In $Ga^{72}$, on the other hand,[1] 75 percent of the beta-ray transitions lead to levels 3 Mev and more above the ground state. This easily accounts for the lack of intensity of the other lines of the spectrum.

The question of the short-lived metastable state connected with the internally converted line corresponding to a gamma-ray at 0.700 Mev still poses an enigma. The ratio of the number of internal conversion electrons to the total number of positrons from $As^{72}$ is 0.012 while the ratio to the total number of beta-rays in $Ga^{72}$ is 0.005. There is no evidence from the analysis of the positrons of $As^{72}$ or the negatrons of $Ga^{72}$ that there is a level at 0.700 Mev above the ground state. If the

[6] M. G. Mayer, Phys. Rev. **78**, 16 (1950).

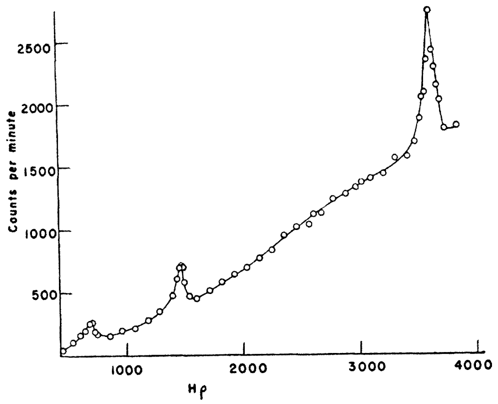


FIG. 3. Internal conversion lines in $As^{72}$, $As^{73}$, and $As^{71}$.

level is placed higher in the level scheme, as was proposed in $Ga^{72}$, it is necessary to assume that its enhanced population in the decay of $As^{72}$ is occasioned by $K$-electron capture.

### IV. REMARKS ON THE SPECTRA OF $As^{74}$, $As^{73}$, $As^{71}$

It has already been noted that the species $As^{74}$, $As^{73}$, and $As^{71}$ were produced in the experiments in which 23-Mev alpha-particles bombarded gallium. While the investigation of these elements was not the main purpose of this research, and since the method of production was not designed to give the maximum yield of these species, still the results obtained appear to be worth mentioning.

#### $As^{74}$

The spectrum of $As^{74}$ (17.5 days) has been studied by several investigators. Sagane, Kojima, Miyamoto, and Ikawa[7] investigated the particle spectrum with the help of a cloud chamber. They found that both negatrons and positrons were emitted. They gave the negatron end point as 1.3 Mev and the positron end point as 0.9 Mev. Deutsch and Roberts,[8] using a magnetic lens spectrograph, have shown that there is a gamma-ray emitted having an energy of 0.582 Mev.

In the present experiments, the gamma-ray (see Fig. 1) was measured together with the gamma-rays of $As^{72}$. The energy of the gamma-ray was found to be 0.593 $\pm 0.003$ Mev. The particle spectrum was measured using a source in which both $As^{71}$ and $As^{73}$ were produced, activation by 10 to 12-Mev alpha-particles, and from which the $As^{72}$ has been allowed to die out. The resulting spectrum was relatively weak but it was possible to make a Fermi plot of the data. The result of the analysis shows two negatron groups of end-point energies 1.45 Mev (47 percent) and 0.82 Mev (53 percent), and one positron group of energy 0.96 Mev. The ratio of electrons to positrons is approximately 2. The mismatch of about 7 percent between the difference in energy of the two electron groups and the gamma-ray energy is caused by the low intensity and complexity of the spectrum

#### $As^{73}$ and $As^{71}$

The spectrum of $As^{73}$ has been investigated by Elliott and Deutsch,[9] using a magnetic lens spectrometer. This isotope decays by $K$-electron capture, with a half-life of 90 to 100 days, and emits internal conversion electrons from a gamma-ray of energy 0.052 Mev. In the present experiments, when 23-Mev alpha-particles bombard gallium, an internal conversion line corresponding to a gamma-ray of 0.052 Mev has been found. This is seen on Fig. 3. The half-life of this line has been measured and found to be approximately 90 days. These experiments confirm the findings of Elliott and Deutsch.

The beta-ray spectrum of arsenic, obtained when 23-Mev alpha-particles are used, also shows a line at 0.162 Mev (see Fig. 3). The decay of this line was followed and was found to show a half-life of about 60 hours. This line is evidently associated with the disintegration of $As^{71}$. Hopkins and Cunningham[10] have ascribed a period of 52 min. to $As^{71}$ and also, according to Seaborg and Perlman,[11] one of 60 hours. The 52-min. activity occurs in the chain

$$Se^{71} \xrightarrow[\text{44 min.}]{\beta+} As^{71} \xrightarrow[\text{52 min.}]{\beta+} Ge^{71} \xrightarrow[\text{40 hr.}]{} Ga^{71}.$$

Since it does not seem possible to associate the line at 0.162 Mev with a 52-min. activity or any of its disintegration products, it is natural to associate it with the 60 hr. $As^{71}$, or possibly with some of its disintegration products if any. Further work will be necessary to work out the final assignment.

The authors wish to express their thanks to Dr. Milo B. Sampson and the cyclotron crew for making the bombardments. They are also indebted to Miss Elma Lanterman for performing the chemical separations.

[7] Sagane, Kojima, Miyamoto, and Ikawa, Proc. Phys. Math. Soc. Japan **21**, 728 (1939).
[8] M. Deutsch and A. Roberts, Phys. Rev. **60**, 362 (1941).
[9] L. G. Elliott and M. Deutsch, Phys. Rev. **63**, 457 (1943).
[10] H. H. Hopkins, Jr. and B. B. Cunningham, Phys. Rev. **73**, 1406 (1948).
[11] G. T. Seaborg and I. Perlman, Rev. Mod. Phys. **20**, 585 (1948).