given energy, either experimentally or by a rather involved calculation.

We have measured the relative photopeak efficiencies for the geometrical spectrometer arrangement discussed above for six monoenergetic gamma rays. This photopeak efficiency is shown in Fig. 2. From the results of this experiment, it was possible to calculate relative strengths of the two gamma rays present from the decay of $Na^{22}$. With the source solid angle the same for both gammas, the ratio of strengths of the two gammas is given by

$$\frac{\gamma_1}{\gamma_2}=\frac{\{1-\exp[-\mu(E_1)x]\}\{F(E_1)\}\{A(E_1)\}}{\{1-\exp[-\mu(E_2)x]\}\{F(E_2)\}\{A(E_2)\}},$$

where $F$ is the photopeak efficiency and $A$ is the photopeak area. A correction to source strengths for the difference in absorption in 0.9 mm of Al was calculated. The calculation of relative source strengths for the two gamma rays showed that $(11.0\pm0.9)$ percent of the disintegrations to the excited state of $Ne^{22}$ are not accompanied by the emission of two 0.511-Mev quanta, and therefore decay by orbital electron capture. This result agrees with the values $(9.9\pm0.6)$ percent obtained by Sherr and Miller[1] and $(11.5\pm5)$ percent obtained by Maeder *et al.*[2]

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# Decay of $_{32}Ge^{75m}$ (49 sec), $_{32}Ge^{77m}$ (52 sec), and $_{32}Ge^{77}$ (12 hr)

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The investigations herein described have been carried out by using a scintillation coincidence spectrometer and 180° focusing magnetic spectrographs. Sources are prepared by the activation of both normal germanium and the enriched isotopes thereof in the Argonne reactor (CP-3′). Three of the neutron-induced activities of germanium are studied.

*$_{32}Ge^{75m}$ (49 sec):* The half-life and isotopic assignment of the activity are confirmed. From internal-conversion measurements, the energy of the isomeric transition is found to be $138.5\pm1.0$ kev, and the K/L ratio estimated to be $\sim3$.

*$_{32}Ge^{77m}$ (52 sec):* The isotopic assignment of the activity is confirmed and the half-life measured to be $52\pm2$ seconds. The isomeric state of $Ge^{77}$ decays by three branches: an isomeric transition of $159\pm3$ kev to the ground state of $Ge^{77}$, an $\sim2.7$-Mev beta ray to a $215\pm3$-kev excited state of $As^{77}$, and an $\sim2.9$-Mev beta ray to the ground state.

*$_{32}Ge^{77}$ (12 hr):* From the scintillation spectrometer measurements, the presence of eighteen gamma rays is deduced. Though beta-gamma and gamma-gamma coincidence experiments these are incorporated into a decay scheme which includes the 52-second isomeric state of $Ge^{77}$ and nine excited states of $As^{77}$.

## APPARATUS AND METHODS

Normal germanium has been found to consist of five stable isotopes. Neutron capture in three of these results in the formation of $Ge^{71}$ (11 day), $Ge^{75m}$ (49 sec), $Ge^{75}$ (80 min), $Ge^{77m}$ (52 sec), and $Ge^{77}$ (12 hr). Previous studies of these activities have not been exhaustive. We have undertaken to investigate the two metastable states, $Ge^{75m}$ and $Ge^{77m}$, and the 12 hour activity of the ground state of $Ge^{77}$.

The scintillation coincidence spectrometer[1] employed in this study is composed of two independent spectrometers, one incorporating a ten-channel pulse-height analyzer, and the other a single-channel analyzer. The ten-channel analyzer is used independently to examine the "normal" pulse-height distribution associated with the source, while both analyzers are employed to search for various coincidence combinations of the peaks found in the normal spectrum. In examining a normal gamma-ray spectrum, the sources are placed approximately six inches from the detecting crystal, and a collimator is interposed. (The collimator consists of a 2-in. lead block through which a $\frac{3}{4}$-in.-diameter hole is bored.) These arrangements serve two purposes: to increase the amplitude of the "photopeak" relative to the Compton distribution and to eliminate the possibility of "sum" peaks caused by the simultaneous detection of two coincident radiations. Many operational details of this instrument have been previously discussed.[2]

The efficiency and resolution of the scintillation coincidence spectrometer have been improved by the installation of larger NaI(Tl) crystals than those previously used and by replacing the R.C.A. type 5819 photomultipliers with Dumont type 6292 tubes. (The resolution is now about 8 percent for the 662-kev gamma ray of $Cs^{137}$.) The new crystals are nearly cubic,

[1] S. Burson and W. Jordon, Phys. Rev. **91**, 498 (1953).

[2] Burson, Jordon, and LeBlanc, Phys. Rev. **94**, 103 (1954).

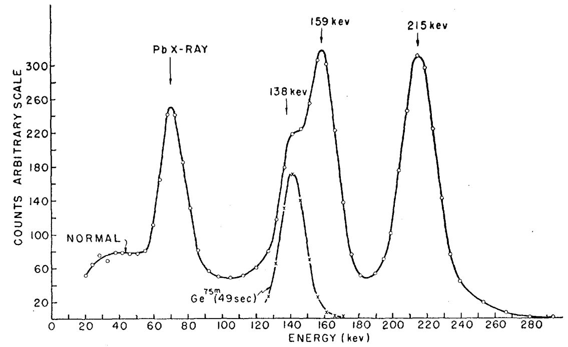


FIG. 1. The pulse-height distribution of $_{32}Ge^{77m}$ (52 sec) and $_{32}Ge^{75m}$ (49 sec).

measuring $2\frac{1}{4}$ in.$\times 2\frac{1}{4}$ in.$\times 2\frac{1}{8}$ in. For beta-ray detection, the NaI crystal in the single-channel arm of the circuit is replaced by an anthracene crystal. This instrument is supplemented by internal-conversion-electron spectrographs[3] which are used, where possible, to ascertain more accurate transition energies. Coincidence measurements yield information relating the various transitions, which, together with the energies, permit a decay scheme to be constructed.

### $Ge^{75m}$ (49 sec)

In 1952, Flammersfeld[4] reported an activity with a half-life of 42 seconds which he assigned to a metastable state of $Ge^{75}$. By means of absorption measurements, he determined the energy of the conversion electrons associated with the activity to be 140 kev. Subsequently, Smith *et al.*[5] reported having independently observed and studied this activity. They assign an energy of about 175 kev to the isomeric transition from scintillation-spectrometer measurements and assign a value of $48\pm2$ seconds for the half-life. From energy-lifetime considerations, they conclude the character of the radiation to be E3. Campbell[6] reports the energy of the isomeric transition to be about 150 kev.

Our measurement of the half-life yielded a value of $49\pm2$ seconds in good agreement with that of Smith *et al.* We have determined the transition energy both by scintillation spectrometer and by internal-conversion-electron measurements. The scintillation spectrometer was calibrated for this measurement with the 159-kev gamma ray of $Te^{123}$, and the energy of the gamma ray was measured to be $142\pm3$ kev (Fig. 1). A more accurate measurement was made using a magnetic electron spectrograph. Fifty irradiations of a source brought out $K$ and $L$ lines on the photographic plates from which the energy is found to be $138.5\pm1.0$ kev. From visual examination of the plate, the $K/L$ ratio is estimated to be greater than 3.

[3] Rutledge, Cork, and Burson, Phys. Rev. **86**, 775 (1952).
[4] A. Flammersfeld, Z. Naturforsch. **7a**, 295 (1952).
[5] Smith, Caird, and Mitchell, Phys. Rev. **88**, 150 (1952).
[6] E. C. Campbell, private communication to Hollander, Perlman, and Seaborg, Revs. Modern Phys. **25**, 504 (1953).

A search was made for other radiations which might be associated with this activity, but none were found. It is thus concluded that $Ge^{75m}$ decays to the ground state of $Ge^{75}$ by means of either the emission of a 138.5-kev gamma ray or of internal-conversion electrons.

### $Ge^{77m}$ (52 sec)

Arnold and Sugarman[7] reported an activity of $59\pm2$ seconds which they assigned to an isomeric state in $Ge^{77}$. They measured the energy of the beta ray to be 2.8 Mev by absorption in aluminum and observed no gamma rays. By means of a scintillation spectrograph, Mitchell and Smith[8] reported the energy of the isomeric transition to be 380 kev.

Our examination of the normal scintillation spectrum shows the presence of two photopeaks associated with this activity. These represent gamma rays with energies of $159\pm3$ and $215\pm3$ kev (Fig. 1). The 159-kev gamma ray of $Te^{123}$ was used for calibration. Although the source was produced by neutron irradiation of enriched $Ge^{76}$, the 138.5-kev gamma ray still appears to be due to incomplete isotopic separation.

By following the decay of the 215-kev peak, the lifetime of the metastable state was found to be $52\pm2$ seconds.

A search for gamma-gamma coincidences showed the two radiations not to be in coincidence. The 215-kev gamma ray was found to be in coincidence with beta rays, while the 159-kev radiation was not (Fig. 2). Absorption measurements in aluminum show the beta ray in coincidence with the 215-kev gamma ray to have a half-thickness of approximately 170 mg/cm$^2$, corresponding to an end-point energy of about 2.7 Mev. From the beta-gamma coincidence measurements we estimate the beta branching to the excited state of $As^{77}$ to be approximately one-tenth of that to the ground state. Thus, it is concluded that the isomeric state of $Ge^{77}$ decays by three branches: an isomeric transition of 159 kev to the ground state of $Ge^{77}$, an

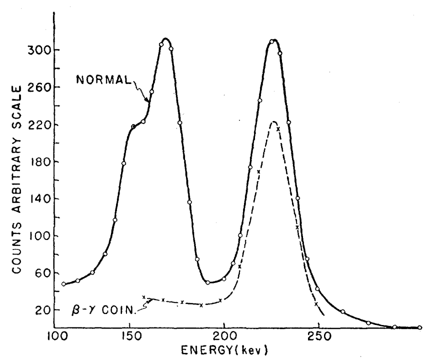


FIG. 2. Beta-gamma coincidence pulse-height distribution of $_{32}Ge^{77m}$ (52 sec).

[7] J. Arnold and N. Sugarman, J. Chem. Phys. **15**, 703 (1947).
[8] A. Mitchell and A. Smith, Phys. Rev. **85**, 153 (1952).

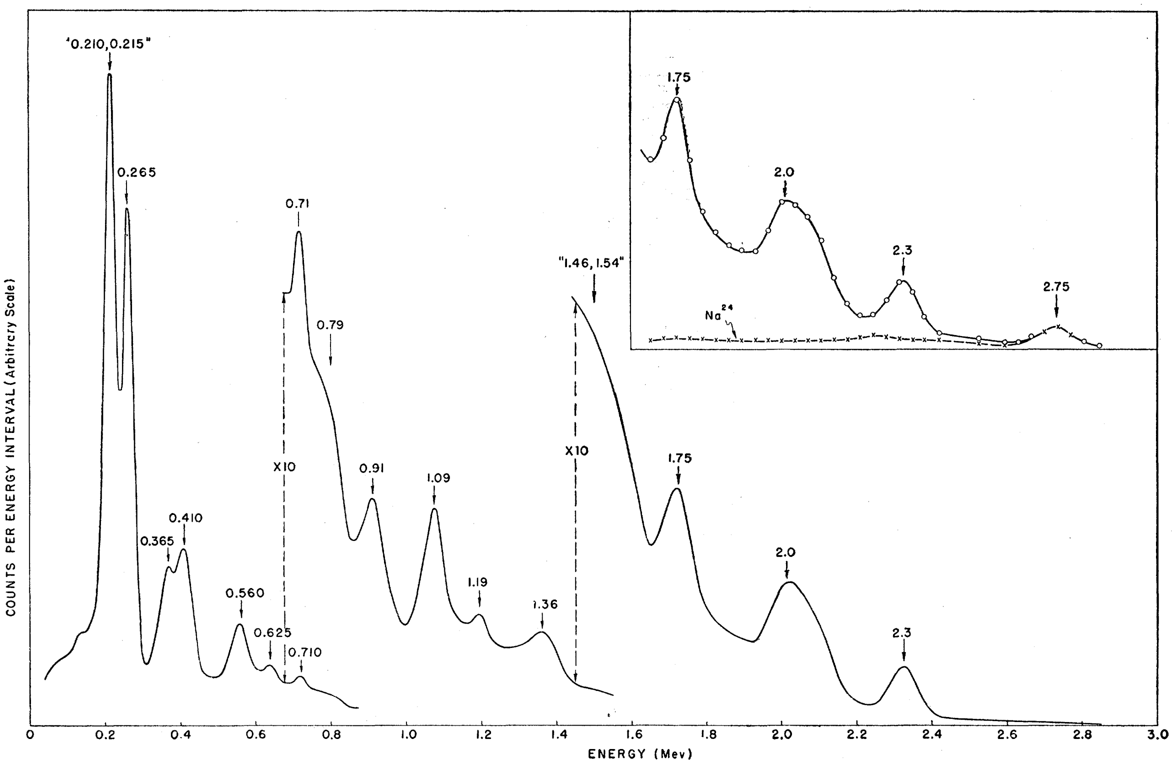


FIG. 3. Normal pulse-height distribution of $_{32}Ge^{77}$ (12 hr).

$\sim$2.7-Mev beta ray to a 215-kev excited state of $As^{77}$, and an $\sim$2.9-Mev beta ray to the ground state.

### $Ge^{77}$ (12 hour)

Sagane[9] produced an activity with a half-life of about eight hours by irradiating germanium with neutrons and deuterons and assigned it to $Ge^{77}$. Seaborg *et al.*[10] confirmed the assignment and measured the half-life to be 12 hours. Sagane *et al.*[11] measured the maximum beta-ray energy to be 1.9 Mev. Steinberg and Engelkemeir[12] measured the beta energy to be 2.0 Mev and also detected gamma radiation. To the beta ray, Mandeville *et al.*[13] assigned a value of 1.74 Mev, verified the generic relationship, showing the 12-hour germanium to be the parent of the 40-hour $As^{77}$, and observed coincidences between the beta rays and gamma rays with a nominal energy of about 0.5 Mev (by absorption methods). Reynolds[14] (also by absorption methods) found an energy value of 1.8 Mev for the beta ray and analyzed the gamma radiation into two components of about 0.3 and 0.6 Mev. He observed coincidences between beta rays and each of the gamma-ray components, and also between two gamma rays, both of about 0.3 Mev, but no coincidences between the 0.3-Mev radiations and those of about 0.6 Mev. Using a lens spectrometer, Smith[15] resolved the beta spectrum into three components, 2.196, 1.379, and 0.710 Mev. From internal conversion and the photo electrons from secondary radiators, he reports thirteen gamma rays. These measurements, together with the results of some coincidence experiments, were used to present a decay scheme. Two more gamma rays of 2.3 and 2.7 Mev were observed by Saraf *et al.*[16] and attributed to the 12-hour $Ge^{77}$.

Our efforts have been directed toward a detailed study of the gamma-ray spectrum and in particular, through extensive coincidence measurements, the construction of a decay scheme. Our result differs markedly from that of Smith, which is not surprising since, in addition to other discrepancies, our scintillation spectrometer revealed the presence of at least eight gamma rays not detected by his apparatus.

### THE GAMMA-RAY SPECTRUM

The normal scintillation pulse-height distribution is shown in Fig. 3. The curve presented represents a

[9] R. Sagane, Phys. Rev. **53**, 212 (1938); Phys. Rev. **55**, 31 (1939).
[10] Seaborg, Livingood, and Friedlander, Phys. Rev. **59**, 320 (1941).
[11] Sagane, Miyamoto, and Ikawa, Phys. Rev. **59**, 904 (1941).
[12] E. Steinberg and D. Engelkemeir, *Radiochemical Studies: The Fission Products* (McGraw-Hill Book Company, Inc., New York, 1951), Paper No. 54, National Nuclear Energy Series, Plutonium Project Record, Vol. 9, Div. IV.
[13] Woo, Mandeville, Scherb, and Keighton, Phys. Rev. **75**, 1286 (1949); Mandeville, Woo, Scherb, Keighton, and Shapiro, Phys. Rev. **75**, 1528 (1949).
[14] S. A. Reynolds, Oak Ridge National Laboratory Report ORNL-867, 24 (unpublished).
[15] A. B. Smith, Phys. Rev. **86**, 98 (1952); A. Smith and A. Mitchell, Phys. Rev. **85**, 153 (1952).
[16] Saraf, Varma, and Mandeville, Phys. Rev. **91**, 1216 (1953).

composite of many experiments. The wide range of intensities (note that the 210-kev peak is approximately 1000 times more intense than the 2.3-Mev peak) required a number of sources of varying strength. For the high-energy regions, lead absorbers were inserted to attenuate the low-energy peaks in order not to overload the amplifier or shift the base line of the discriminator circuits. While experimental points are not shown, the channels used were narrow enough to insure that every peak or inflection in the distribution be defined by several points (e.g., inset Fig. 3). Counting was always continued long enough so that the statistical accuracy of the curve is comparable to the thickness of the line defining it. The data for the distribution were accumulated by bracketing a portion of the spectrum with the ten-channel analyzer and moving the discriminator to an adjacent region to allow several channels to overlap. This process was repeated until the entire spectrum was covered. Whenever the amplifier gain was changed, different sources employed, or the lead filters inserted, the sections of the spectrum were normalized by matching the overlapping portions.

In the distribution, fourteen peaks are resolved. The most intense peak at about 210 kev, hereafter referred to as the 210,215 peak, will later be shown to be complex and to represent two gamma rays, one of 210 and one of 215 kev. The coincidence measurements also show that the shoulder on the high-energy side of the 710-kev peak represents the photopeak of a gamma ray of about 790 kev. While no other experiments explain the significance of the shoulder at about 1.5 Mev, the decay scheme proposed does provide for transitions of about this energy. The shoulder is too intense to be accounted for by attributing it to Compton distributions or other secondary effects of the gamma rays of

TABLE I. Gamma rays associated with $_{32}Ge^{77}$(12 hr).

| Present investigation | Smith | Saraf *et al.* |
|---|---|---|
| | 0.042 | |
| | 0.073 | |
| 0.210±0.001 | | |
| 0.215±0.003 | 0.213 | |
| 0.265±0.001 | 0.264 | |
| | 0.300 | |
| | 0.327 | |
| 0.365±0.007 | 0.368 | |
| 0.410±0.008 | 0.408 | |
| | 0.418 | |
| | 0.466 | |
| 0.560±0.010 | 0.564 | |
| 0.625±0.015 | | |
| 0.710±0.015 | | |
| 0.79 ±0.02 | | |
| 0.91 ±0.02 | | |
| 1.09 ±0.02 | 1.105 | |
| 1.19 ±0.02 | | |
| 1.36 ±0.03 | | |
| 1.46 } Unresolved | | |
| 1.54 } | | |
| 1.75 ±0.03 | 1.75 | |
| 2.00 ±0.05 | | |
| 2.30 ±0.05 | | 2.3 |
| | | 2.7 |

higher energy. The somewhat broad appearance of the peak at 2.0 Mev is worthy of note. The distortion on the high-energy side is interpreted as being due to the Compton distribution from the 2.3-Mev gamma ray.

A peak appeared at 2.75 Mev whose amplitude was approximately one-third that of the 2.3-Mev peak. (Inset Fig. 3.) This peak is seen to coincide exactly with the distribution associated with the 2.75-Mev gamma ray of $Na^{24}$ (dashed curve). Since the amplitude of this photopeak was found to be several times greater in the samples of enriched germanium than in the normal germanium, it was evident that the enriched isotope contained a small impurity of sodium. Because of the exact energy fit and the low intensity, this radiation was attributed to a sodium contamination in the other samples as well. To correct for the effect of the contamination, a pure $Na^{24}$ spectrum was normalized to the Ge distribution at the 2.75-Mev peak as shown in the inset in Fig. 3, and subtracted from the spectrum. While we cannot say with certainty that there is no 2.75-Mev gamma ray present in the $Ge^{77}$ spectrum, we have concluded this to be the case. The spectrum of $Ga^{72}$ (14 hour) was also examined and compared with that of $Ge^{77}$. It was concluded that Ga was not present as a contamination. In our scintillation spectrum, when the lead collimator was in use, a peak was present at about 73 kev. To determine whether this peak in part represented a gamma ray or was entirely due to secondary radiation, the lead shielding was replaced by concrete blocks. It was then found that the 73-kev peak had vanished and the only rise in the distribution between about 20 and 200 kev could be attributed to the Compton electrons from the higher energy gamma rays. We also found no evidence for the gamma rays of 300, 327, 425, or 466 kev.

Only two of the gamma rays were measured by internal conversion, the 210- and the 265-kev radiations. While a faint $K$ line for the 215-kev gamma ray was visible, it was not well enough defined to be considered as a reliable datum.

Table I lists all of the gamma rays observed by us, including those detected only through coincidence measurements. For purposes of convenient comparison, the gamma rays reported by Smith and by Saraf *et al.* are also listed.

## COINCIDENCE MEASUREMENTS AND DECAY SCHEMES

In the following paragraphs, the coincidence experiments are discussed together with the development of the decay scheme. Table II presents a summary of the coincidence results. The letter $A$ designates that the combination indicated was observed with certainty and that the interpretation is deemed to be reliable. The letter $B$ indicates that coincidences were observed, but that some ambiguity or other element of uncertainty exists. The numbers refer to the associated paragraph in which experimental details are discussed.

TABLE II. Summary of $\beta$-$\gamma$ and $\gamma$-$\gamma$ coincidence measurements on $_{32}Ge^{77}$ (12 hr).

| | Gamma rays (Mev) 0.210 | 0.215 | 0.265 | 0.365 | 0.410 | 0.560 | 0.625 | 0.71 | 0.80 | 0.91 | 1.09 | 1.19 | 1.36 | 1.46 | 1.54 | 1.75 | 2.0 | 2.3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Beta ~1.3 | | | | | | | | | | | *B*11 | | | | | | | |
| Beta ~1.5 | *B*6 | | *B*6 | *B*6 | *B*6 | *A*6 | | | | | | | | | | | | |
| Beta ~2.1 | *B*4 | | *A*4 | *A*4 | *A*4 | | | | | | | | | | | | | |
| Gamma rays (Mev) 2.3 | | | | | | | | | | | | | | | | | | |
| 2.0 | | | | | | | | | | | | | | | | | | |
| 1.75 | *B*8 | | *B*8 | *B*8 | *B*8 | | | | | | | | | | | | | |
| 1.54 | | | | | | | | | | | | | | | | | | |
| 1.46 | | | | | | | | | | | | | | | | | | |
| 1.36 | *B*7 | | *A*7 | *A*7 | *A*7 | | *B*7 | | | | | | | | | | | |
| 1.19 | | | *A*9 | | | | | | | | | | | | | | | |
| 1.09 | | | | | | | | | | | | | | | | | | |
| 0.91 | *B*10 | | *A*10 | *B*10 | *B*10 | | | | | | | | | | | | | |
| 0.80 | *B*7 | | *A*7 | *A*7 | *A*7 | *A*7 | | | | | | | | | | | | |
| 0.71 | | | | | | | | | | | | | | | | | | |
| 0.625 | | | | | | *A*5 | | | | | | | | | | | | |
| 0.560 | | *B*5 | *A*5 | *A*5 | *A*5 | | | | | | | | | | | | | |
| 0.410 | | *A*1 | | | | | | | | | | | | | | | | |
| 0.365 | | | *A*2 | | | | | | | | | | | | | | | |
| 0.265 | *A*3 | | | | | | | | | | | | | | | | | |
| 0.215 | | | | | | | | | | | | | | | | | | |

Referring to the decay scheme, Fig. 6, the energy levels up to and including the 625-kev state are established from the following evidence:

(1) From Fig. 4 (*a* and *d*), it is apparent that the 410-kev gamma ray is in coincidence with at least one of the gamma rays represented by the 210,215-kev peak (later shown, in paragraph 3, to be the 215-kev). The fact that the energy sum is equal within statistical limits to 625-kev suggests that these coincident radiations are adjacent in the cascade and that the 625-kev gamma ray represents the crossover transition.

(2) A similar argument to (1) holds for the 265- and 365-kev gamma rays which are also seen to be in coincidence from Fig. 4 (*b* and *c*).

The hypothesis that these two cascades, each totaling 625 kev, are in parallel is substantiated by the fact that no coincidences are observed between the 625-kev peak and any of these radiations, Fig. 4 (*a* and *d*). It is further apparent from energy considerations that if the two double cascades originate from the 625-kev level, no coincidences should be observed between the 410-kev gamma ray and either the 265- or 365-kev radiations. From Fig. 4 (*b*, *c*, and *d*) this is seen to be the case.

(3) It will now become evident why the peak referred to as 210,215 kev must be interpreted as being representative of two different gamma rays. If this peak represents only a single transition, the strong coincidences with the 265-kev peak seen in Fig. 4 (*a* and *b*) can only be accounted for if a third "coupling" transition of about 145 kev were present. There is no evidence for a transition of this energy with sufficient intensity to account for the observed coincidences. The coincidences which do appear in the spectra in the region of 150 kev may reasonably be attributed to scattering effects. The coincidences between the 265 and 210,215 peaks cannot be accounted for by scattering. Distributions similar to those shown in Fig. 4(*a*) and (*b*) were obtained when the probes were arranged with their axes at 90° and shielded from each other with a lead block. The possibility was therefore investigated that one of the two peaks represented two gamma rays. The ten-channel analyzer was set to define the 210,215-kev peak. Without changing any adjustments on the apparatus, coincidence distributions were obtained in immediate succession with the 265- and 410-kev peaks. The distribution in coincidence with the 410-kev peak, Fig. 5(*b*), is seen to be shifted upward in energy from the normal distribution, Fig. 5(*a*), and that in coincidence with the 265-kev peak, Fig. 5(*c*), is seen to be shifted downward. The difference in energy between the two peaks is about 5 kev. The experiment was repeated several times. Counting was continued long enough to insure that the observed shift was well outside that which would be possible due to statistical fluctuations. It could thus be concluded that the 210,215-kev peak in fact represents two different gamma rays.

This result obviates the apparent anomaly in the coincidence experiments. A similar experiment was done with the ten-channel analyzer covering the 265-kev peak. No such shift was observed between the coincidence distributions taken with the 210,215- and the 365-kev peaks.

The sequence of the 410–215-kev cascade is established as follows:

Recall that the 52-second metastable state in $Ge^{77}$ decays by means of a beta ray of about 2.7 Mev to an excited state of $As^{77}$. The gamma ray associated with this transition is seen to be in the neighborhood of 210,215 kev. The pulse-height distribution associated with this gamma ray was determined during the course of the coincidence measurements just described, and it can be seen from Fig. 5(*d*) that this radiation is

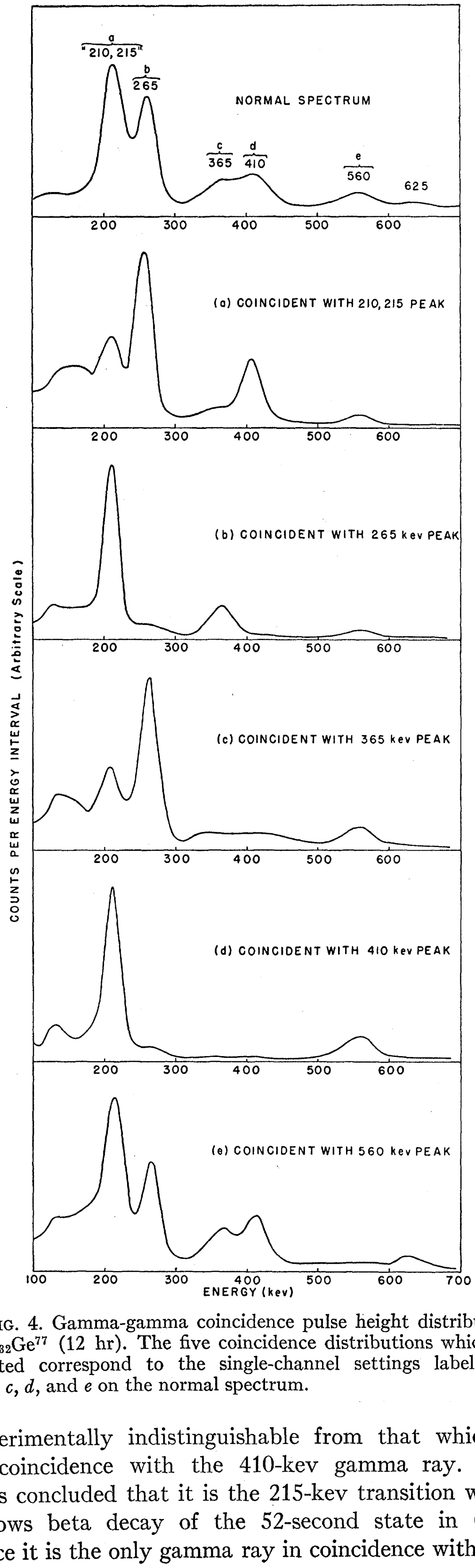


FIG. 4. Gamma-gamma coincidence pulse height distributions for $_{32}Ge^{77}$ (12 hr). The five coincidence distributions which are plotted correspond to the single-channel settings labeled as *a*, *b*, *c*, *d*, and *e* on the normal spectrum.

experimentally indistinguishable from that which is in coincidence with the 410-kev gamma ray. It is thus concluded that it is the 215-kev transition which follows beta decay of the 52-second state in $Ge^{77}$. Since it is the only gamma ray in coincidence with this beta ray, it must lead to the ground state of $As^{77}$. Thus, the 410-kev gamma ray must represent a transition between the 625-kev level and the 215-kev state.

The sequence of the 265–365-kev cascade (2) will now be considered. The 265-kev transition is placed at the bottom of the cascade since it is the only one of the five low-energy transitions seen to be in coincidence with the high energy gamma ray of 1.19 Mev. The arrangement also provides a reasonable explanation for the 210–265-kev coincidences if an energy level is placed at 475 kev.

(4) All of the foregoing arguments concerning the low-lying levels are consistent with the beta-gamma coincidence measurements. The half-thickness in aluminum for the beta rays in coincidence with each of the peaks, "210,215," 265, 365, and 410, was determined. In each case, in addition to a weak low-energy component, a value of about 120 mg/cm² was observed which corresponds to a beta transition energy of approximately 2.1 Mev. Taking into consideration the weak intensity of the higher-energy gamma rays, it may be concluded that a beta transition of approximately 2.1 Mev feeds the 625-kev state. A beta branch feeding the 475-kev level is required to explain the strong 210–265-kev coincidences. It is not surprising that these two branches are not resolved in the absorption experiments since they differ by only about 145 kev.

(5) Consider the level at 1.185 Mev (Fig. 6). The 560-kev gamma ray is seen to be in coincidence with those represented by all the other low-energy peaks including the one at 625 kev, Fig. 4(*a*–*e*). This suggests that the 560-kev transition feeds the 625-kev level. Notice that in the coincidence distribution taken with the 560-kev peak (Fig. 4*e*) the two peaks at "210,215" and 265 kev are lower in intensity relative to the 365- and 410-kev peaks than in the normal distribution. This effect may be attributed to the fact that only a portion of the "210,215" and 265-kev peaks are fed by the 560-kev gamma ray, the remainder following beta decay to the 475-kev level. As a result of these interpretations, the placement of the state at 1.185 Mev in the level scheme is justified.

(6) Beta-gamma coincidence measurements confirm this placement. The half-thickness in aluminum for the beta rays in coincidence with the 560-kev peak was found to be about 70 mg/cm², corresponding to a beta-transition energy of about 1.5 Mev. Coincidence between this beta branch and the lower energy gamma transitions may also account for the complex structure of the other absorption curves previously mentioned.

(7) The energy level at 2.0 Mev is established from the following: The slight shoulder apparent at about 800 kev in the normal distribution stood out definitely as a separated peak in the coincidence distribution whenever the single channel was set to cover any one of the low-energy peaks, including the 560-kev and 625-kev ones. Typical of this effect is the distribution shown in Fig. 7, which was obtained with the single

channel covering the 265-kev peak. These coincidences with all of these different peaks indicate not only the presence of a transition of ~790 kev, but that it must be placed above the 560-kev transition in the energy level scheme. If the 790–560 coincidences represent a two-step cascade, then there must be a level at about 2.0 Mev. This hypothesis is supported by the fact that a peak corresponding to a gamma ray of about 2.0 Mev is present in the normal spectrum. The gamma ray of 1.36 Mev is then readily interpreted as the transition from the 2.0-Mev state to the 625-kev level. The coincidence data substantiate this interpretation, for the 1.36-Mev radiation, while not in coincidence with the 560-kev gamma ray, is found to be in coincidence with all the low-energy peaks, including the one at 625 kev.

(8) The experimental energy difference between the two peaks at 2.3 and 1.75 Mev is consistent with interpreting the former as a transition to the ground state from a level at about 2.3 Mev and the latter as a transition to the 625-kev state. In fact, counting for several hours did provide evidence that the 1.75-Mev peak was in coincidence with the low-energy gamma rays.

(9) The state at 1.46 Mev is established on the basis of experiments which show that coincidences exist between the 265-kev gamma ray and the 1.19-Mev radiation represented by a small peak in the normal distribution. This peak was seen to stand out strongly only when the single channel was covering the 265-kev peak, Fig. 7, and essentially vanished when the single channel was accepting pulses from any of the other peaks. (The 1.19-Mev radiation might be interpreted as arising from a transition from the 1.185-Mev level to the ground state. This would necessitate a second 265-kev radiation above that level in order to explain the coincidences. The assignment indicated is preferred, although it is not unlikely that some branching to the ground state from the 1.185-Mev level is also represented in the 1.19-Mev peak.)

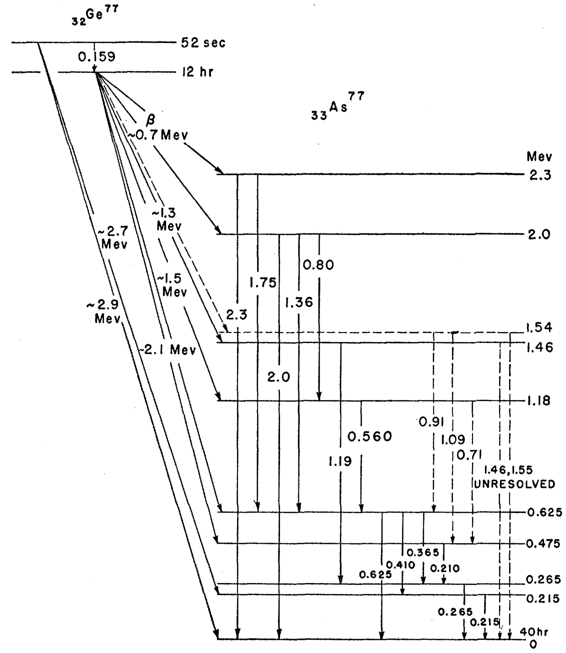


FIG. 6. Decay scheme of $_{32}Ge^{77}$.

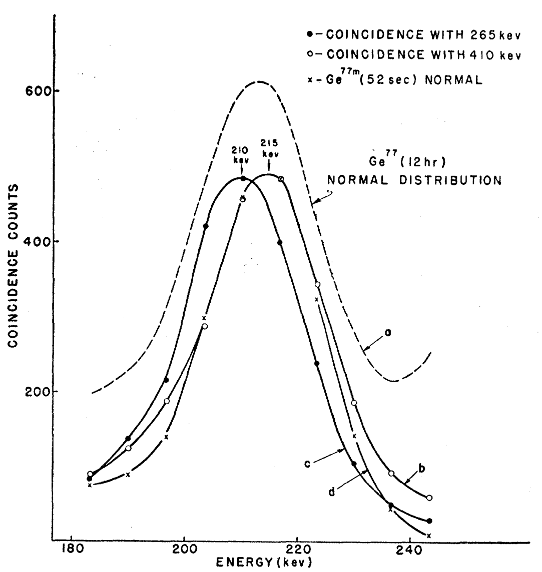


FIG. 5. Resolution of the 210- and 215-kev photopeaks. (*a*) Normal pulse-height distribution of $_{32}Ge^{77}$ (12 hr). (*b*) In coincidence with 410-kev photopeak. (*c*) In coincidence with the 265-kev photopeak. (*d*) Normal distribution of $_{32}Ge^{77m}$ (52 sec).

(10) The existence of the level at 1.54 Mev is deduced from experiments which indicate that the 910-kev peak represents a transition feeding the 625-kev level. The 910-kev peak was seen to be in coincidence with the four peaks, "210,215," 265 (see Fig. 7), 365, and 410, but not with the 560-kev peak. Because of its weak intensity, it is not clear whether coincidences also exist with the 625-kev peak as would be expected.

The rise in the normal spectrum in the neighborhood of 1.5 Mev may thus be interpreted as arising from transitions from either the 1.46-Mev or the 1.54-Mev level to the ground state, or a mixture of both.

(11) The foregoing discussion has disposed of all the gamma rays in the spectrum except two, the 710-kev and the 1.09-Mev radiations. They are included in the arrangement on the basis of their energy alone. The only gamma-gamma coincidences observed with the 710-kev peak seemed to be associated with other radiation of about the same energy (perhaps 790-kev); however, no clear result could be obtained because of the low intensity. All efforts to find coincidences between the 1.09-Mev peak and any of the others met with failure. An aluminum absorption curve of the beta rays in coincidence with the 1.09-Mev peak showed a half-value thickness of about 55 mg/cm$^2$. The corresponding beta-ray energy is about 1.3 Mev, but

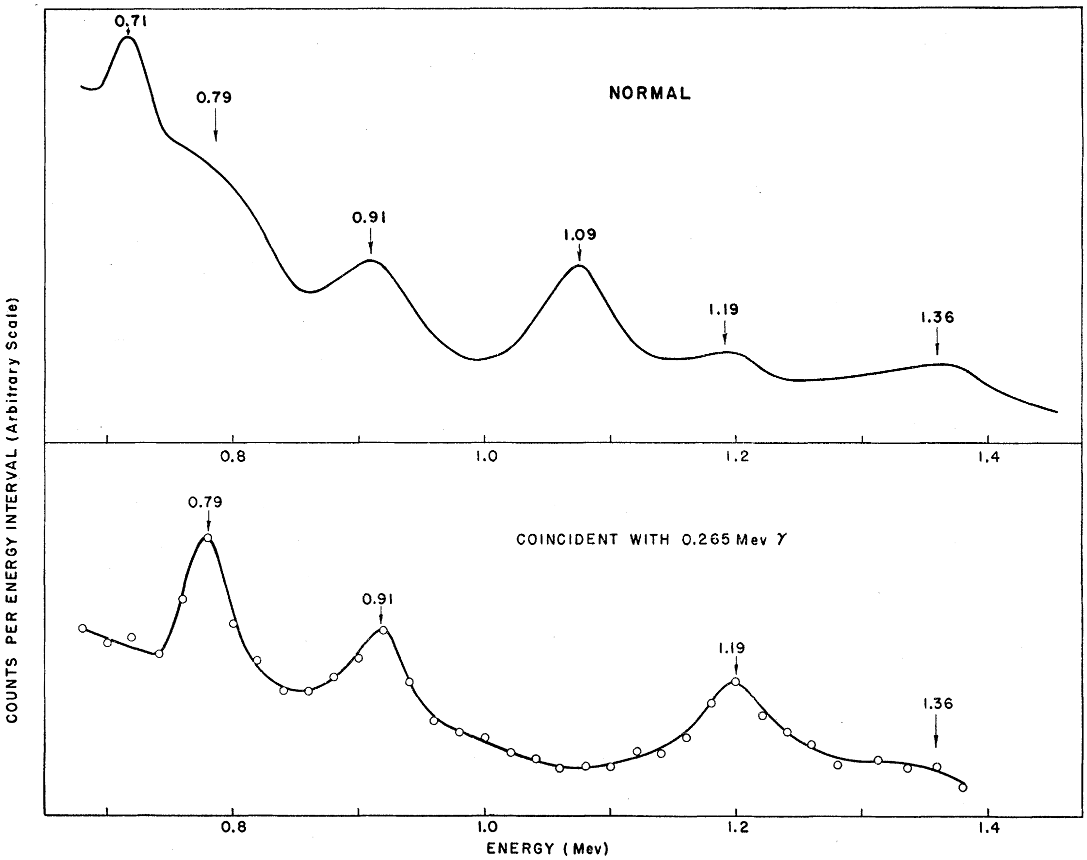


Fig. 7. Pulse-height distribution of high-energy gamma rays which are in coincidence with the 265-kev photopeak.

because of the low counting rates, rather wide limits of error must be allowed. If the 475-kev state is metastable with a lifetime long compared to the 1.6-microsecond resolving time of the coincidence circuit, the arrangement shown is a possible one and is consistent with the beta-gamma coincidence measurements.

Because of the weak intensity of the gamma rays above 600 kev, the beta-gamma coincidence measurements involving those peaks are not considered useful as evidence. The scheme proposed is not considered to be at variance with the measurements by Smith on the beta spectrum. As previously suggested, the two branches feeding the 475- and 625-kev levels would not be resolvable because of their small difference in energy and might appear as a single group in his beta spectrometer analysis. Likewise, the three components feeding the 1.18-, 1.46-, and 1.54-Mev states may also be grouped and identified with Smith's value of 1.379 Mev. Because of the low intensity of the gamma rays emitted during decay of the 2.0- and 2.3-Mev states, no attempt was made to resolve the beta rays feeding these levels. The single groups referred to as 0.710-Mev by Smith may be composed of the two branches required to feed these states. Those portions of the decay scheme indicated by solid lines are considered to be reasonably well established from the experiments, while the portions in dotted lines are considered suggestive only.