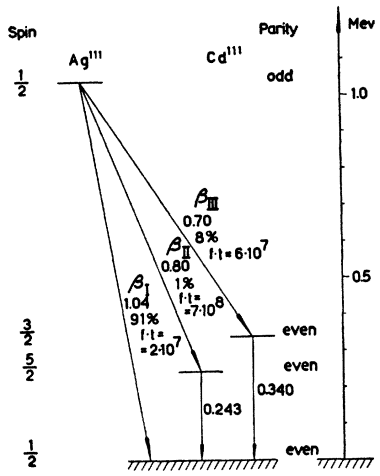

FIG. 2. Disintegration scheme of Ag^{111}.

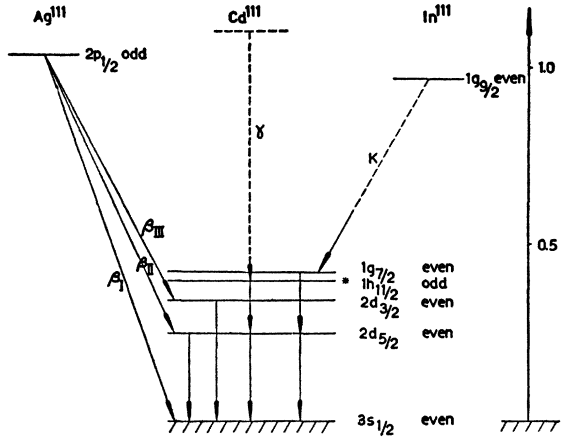

FIG. 3. Term scheme of Ag^{111}, Cd^{111m}, and In^{111}.

The spins given in Fig. 2 are based on the following arguments. The spin of Cd^{111} in the ground state is known to be 1/2. From the beta-spectrum the conversion coefficient of the 340-kev gamma-ray is determined to be ~0.015 and the conversion coefficient of the 243-kev gamma-ray is estimated to be <0.08. Using the calculated values[7] the transitions are found to be electric quadrupole or a mixture of electric quadrupole and magnetic dipole, i.e., the spins of the excited levels are 5/2 or 3/2.

The *ft*-values are given in Fig. 2. According to the rules given by Nordheim[8] the components β_I and β_{III} are first forbidden with $\Delta L=1$ and $\Delta I=0$ or 1, which would give a spin 1/2 or 3/2 for Ag^{111}. The high *ft*-value for β_{II} suggests that this can be a transition with $\Delta L=1$ and $\Delta I=2$. (In that case the beta-spectrum should differ from the allowed shape, but as the intensity is only ~1 percent it is impossible to see it from the Fermi plot.) If this is assumed, one gets the spins given in Fig. 2. From half-life measurements Deutsch and Stevenson[9] have found that the 247-kev (from In^{111}) gamma-transition ($\tau=(8\pm1)\cdot10^{-8}$ sec.) is probably electric quadrupole. This gives some support for spin 5/2 for the first excited level.

Spins and parities in the Ag^{111} disintegration scheme are in agreement with the spin-orbit coupling scheme of the nuclear shell model.[10,11] The quantum state of the ground level would then be $3s_{1/2}$, the first excited level $2d_{5/2}$ and the second $2d_{3/2}$. For Ag^{111} the spin-orbit scheme predicts spin 1/2 or 9/2 but from the *ft*-values 9/2 is impossible, leaving as the only alternative for Ag^{111} to be a $2p_{1/2}$ state, which gives $\Delta L=1$ for the beta-transitions.

In Fig. 3 a complete term scheme[5,6,12] is given for Ag^{111}, Cd^{111m}, and In^{111}. According to this scheme Cd^{111} possesses four excited levels one of which is metastable with the spin 11/2. It is interesting to note that the spin-orbit coupling scheme predicts all these low excited levels and no more for an odd neutron in the shell between the magic numbers 50 and 82.

The transition $1g_{7/2}-2d_{5/2}$ with an energy of 173 kev should be a mixture of electric quadrupole and magnetic dipole radiation. The internal conversion coefficient of this line has been measured before[2] and was found to be 0.18, which is consistent with the calculated values[7] $\alpha_2=0.17$ and $\beta_1=0.092$. The gamma-transition from the excited level should have $\Delta I=3$ and change in parity which gives electric 2^3 pole radiation. This however is not in agreement with the classification by Axel and Dancoff.[13]

Details of the investigation, also describing the chemical procedure, will be given in *Arkiv för Fysik*.

The author wishes to express his gratitude to Dr. Kai Siegbahn for many helpful discussions.

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The Radiations of Ce^{141} and Pa^{233}

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June 16, 1950

OUR studies of the radiations of Ce^{141} result in essential confirmation of the findings of Shepherd[1] and indicate the source of the disagreement with the results of Ter-Pogossian *et al.*[2] with respect to their reported 315 kev gamma-ray. The alleged 70 μsec. state[3] in Pr^{141} was sought in vain.

Cerium oxide samples irradiated in the Clinton and Argonne piles were purified (after the 33 hr. Ce^{143} had decayed) by fluoride and iodate precipitations, including specific separation of praseodymium activity. A Zr $(IO_3)_4$ scavenging was made to separate suspected zirconium and hafnium impurities. Uniformly spread spectrometer samples of <0.2 mg/cm² were prepared on LC-600 films (rendered conductive with Aquadag) by precipitating the fluoride in a drop of $CeCl_3$ solution on the film using hydrogen fluoride vapor.

The electron spectrum (Fig. 1) obtained in our automatic recording double lens spectrometer showed two allowed shape components (see Kurie plot, Fig. 2) with $E_0=0.581\pm0.003$ Mev and $E_0=0.442\pm0.003$ Mev although the *ft*-values (5.16×10^7 and 9.8×10^6, respectively) indicate empirically first-forbidden transitions. On the basis of both shapes being allowed the intensities are 33 percent and 67 percent, respectively.

Conversion lines at 102.9 kev and 138 kev which arise in the *K* and *L* conversion of a gamma of 145 kev were found. No conversion electrons corresponding[4] to a 137.1 gamma-ray appeared.

Photo-electron spectra with ~2 mg/cm² gold radiators revealed only *K* and *L* lines of the 145 kev gamma, whereas the photoelectron spectrum of unpurified CeO_2 showed, in addition to the 145 kev gamma, a strong 316 kev gamma and others of lower intensity. The 316 kev gamma-emitter followed zirconium during purification of the cerium. Measurement of the extraction coeffi-

TABLE I. 32 .5 day Ce^{141}; multipolarity of gamma-radiation.

Multipolarity l	Lifetime[a] (sec.)	K conv. coeff.[b] $(N\epsilon/N\gamma)$ Electric	Magnetic	K/L ratio Electric[c]	Magnetic[d]
1	1.26×10^{-16}	0.080	0.43	9.5	11.9
2	8.1×10^{-9}	0.42	2.80	4.6	8.6
3	2.34×10^{-3}	1.68		1.9	4.5
Experimental value	$<10^{-8}$	0.254[e]		5.5	

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[b] Rose, Goertzel, Spinrad, Harr, and Strong, AECU-550 (October 18, 1949), (unpublished).
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[e] Value from spectrometer data.

cient in di-isopropylketone indicated that it was probably Pa^{233} resulting from the neutron activation of the thorium impurity in the CeO_2, although spectroscopic analysis showed $<10^{-4}$ part of thorium. The half-life[2] of Pa^{233} is 27.4 days, quite close to our value[5] of 32.5 ± 0.2 days, for a pure sample of Ce^{141} followed on an ionization chamber. No tailing off of the decay over seven lives is observed.

The electron spectrum of the impurity activity shows conversion lines at 288, 221, 192, 77.5, 61, and 50 kev, all but the last matching the observations of Haggstrom[6] on the Pa^{233} spectrum. The beta-continuum, however, extends beyond her reported maximum of 230 kev to ~530 kev in weak intensity, which corresponds to the total decay energy expected.[7] The identification of the impurity as Pa^{233} is thus confirmed, presumably also in the samples of Ter-Pogossian *et al.*[2]

Beta-gamma-coincidence measurement with scintillation detectors indicated an ~420 kev beta in coincidence[2,8] with ~150 kev gamma, and that the higher beta was followed by little if any gamma-ray energy. The decay scheme of Fig. 3 is thus indicated. The conversion coefficient deduced from coincidence measurements $[N(\epsilon)/N(\gamma)]$ is 0.7, in disagreement with the value from the spectrometer data of 0.254. The reason for this is not understood. With a resolving time $2T=5\times10^{-8}$ sec. using stilbene crystal detectors, delayed β-γ-coincidences were sought, and an upper limit on the gamma-emission lifetime of $<10^{-8}$ sec. was established, in agreement with the observations of Bunyan *et al.*[9]

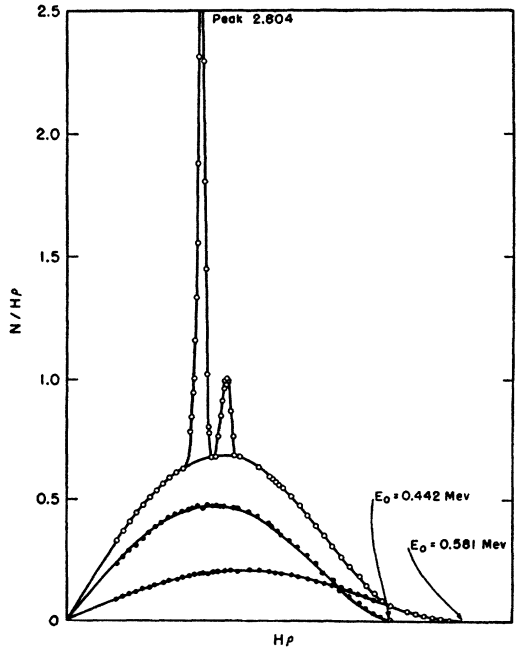

FIG. 1. Momentum spectrum of Ce^{141}.

Although there is observed an asymmetry of very low intensity in the resolving time curve for Ce^{141} it does not exhibit an exponential time dependence, and certainly cannot be ascribed to the 70 μsec. period reported by Hirzel *et al.*[3]

The data on the gamma-radiation is given in Table I. From the upper limit on the half-life of the gamma-transition one can eliminate any gamma-polarity higher than quadrupole. The spectrometer value for the K conversion coefficient is consistent with either EQ or MD radiation and the K/L conversion ratio restricts the choice to EQ.

According to the nuclear shell model proposed by Maria Mayer,[10] the predicted level assignments are as follows: For Pr^{141}, $d_{5/2}$ (the spin has been measured[11] as 5/2); for Ce^{141}, either $h_{9/2}$ or $f_{7/2}$, the former considered the more likely, and for the 145 kev level in Pr^{141}, $g_{7/2}$. The gamma-transition, if $g_{7/2}-d_{5/2}(|J-J'|=1, 2\cdots6$; no parity change), permitting electric quadrupole or magnetic dipole radiation,[12] is consistent with our observation. For the $f_{7/2}$ assignment in Ce^{141}, the low and high energy beta-transitions would be $\Delta J=0$, yes, and $\Delta J=-1$, yes, respectively, and for the $h_{9/2}$ assignment, $\Delta J=-1$, yes, and $\Delta J=-2$, yes, all leading to first-forbidden interactions[13] with either Fermi or Gamow-Teller selection rules, except the last, which requires the Gamow-Teller rules. In this case ($\Delta J=2$, yes) only, a non-linear Kurie plot is predicted, which suggests, on the basis of the short but quite linear portion of the Kurie curve of the higher energy beta (Fig. 2), that the $f_{7/2}$ assignment is correct or that G-T rules do not apply.

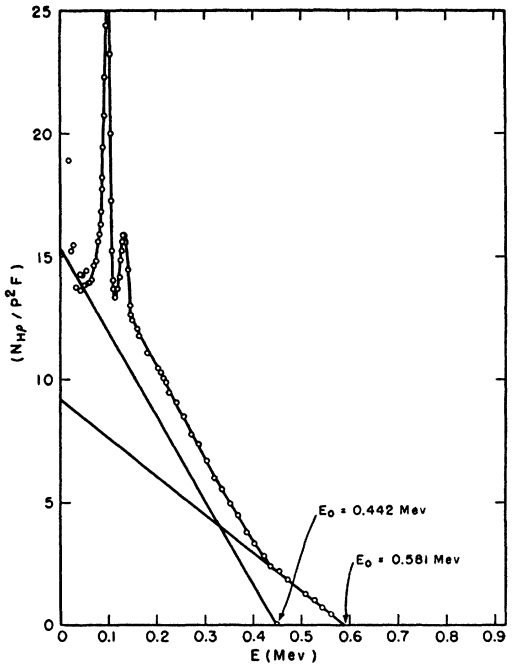

FIG. 2. Kurie plot of Ce^{141} spectrum. Relativistic Fermi function used.

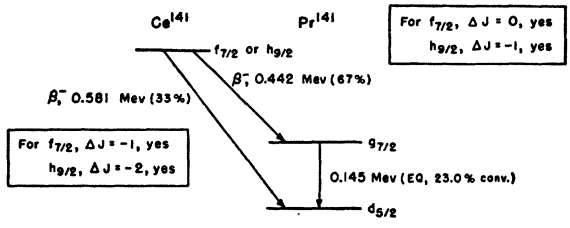

FIG. 3. Decay scheme of Ce^{141}.

We wish to thank Frank Wagner, Jr. for assistance in operating the spectrometer and Jack May for his aid in the computations. A more detailed report of this work will be submitted to this Journal.

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Temperature Dependence of the Energy Gap in Germanium from Conductivity and Hall Data*

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July 5, 1950

OPTICAL absorption experiments, measurements of the threshold of internal photoelectric effects, and consideration of crystal volume change with temperature all show that the energy gaps in silicon and germanium decrease with rising temperature.[1] The same result has been obtained by analysis of the high temperature resistivity and Hall data for silicon.[2] We describe here the calculation of the temperature dependence of the energy gap in germanium from high temperature (500°K to 850°K) conductivity and Hall data.

The free electron concentration, n_e, and hole concentration, n_h, in a semiconductor in thermal equilibrium[3] are related by

$$n_e n_h = A^2 T^3 \exp(-E_G/kT), \tag{1}$$

where E_G is the energy gap between the full and conduction bands, and

$$A^2 = 32h^{-6}(m_e m_h)^{\frac{3}{2}}(\pi k)^3, \tag{2}$$

where k is the Boltzmann constant, h the Planck constant, and m_e and m_h the effective electron and hole masses. If $m_e \approx m_h \approx m_0$, the free electron mass, then $A = 4.84\times10^{15}$ cm^{-3} deg.$^{-\frac{3}{2}}$. If one writes

$$E_G = E_G^0 + (\partial E_G/\partial T)T, \tag{3}$$

then

$$(n_e n_h/T^3)^{\frac{1}{2}} = A' \exp\{-E_G^0/(2kT)\}, \tag{4}$$

where

$$A' = A \exp\{-(\partial E_G/\partial T)/(2k)\}. \tag{5}$$

The n_e and n_h values at various temperatures, high enough for impurity scattering to be negligible, were calculated from the measured conductivity (σ) and Hall coefficient (R) curves for several N-type germanium samples.[4] First, c, the ratio of electron to hole mobility, is calculated from

$$1 - \frac{1}{c} = \frac{-3\pi eR(\sigma/eb_e)^2/8 - N}{(\sigma/eb_e) - N}, \tag{6}$$

where b_e is the electron mobility and N the electron density at exhaustion. In view of recent measurements[5] and calculations[6] pertaining to electron mobility in germanium, we used $b_e = 17\times10^6 T^{-\frac{3}{2}}$ cm²/volt-sec. Thus c is found to be approximately 1.5 for all samples. Then n_h is calculated from

$$n_h = \{(\sigma/eb_e) - N\}(1 + 1/c)^{-1}, \tag{7}$$

and n_e from $n_h + N$. When $\ln\{(n_e n_h)^{\frac{1}{2}}/T^{\frac{3}{2}}\}$ is plotted *vs.* $1/T$, a straight line is obtained for each sample (Fig. 1). The slope is

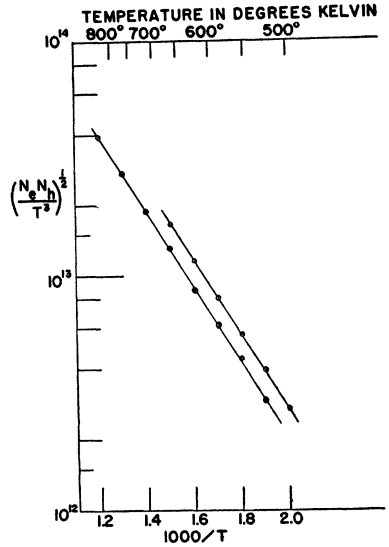

FIG. 1. Plot of $(n_e n_h/T^3)^{\frac{1}{2}}$ *vs.* $1/T$ for two of the germanium samples investigated. The n_e and n_h values are calculated from measured conductivities and Hall curves.

essentially the same for each sample and its value determines E_G^0 as about 0.73 ev. The average of the intercepts gives $A' = 9.2\times10^{15}$ cm^{-3} deg.$^{-\frac{3}{2}}$. By use of Eq. (5), one obtains $\partial E_G/\partial T = (-1.1\pm0.1)\times10^{-4}$ ev/°K if $(m_e m_h/m_0^2)^{\frac{3}{4}} = 1$. This value compares well with the value calculated by Fan[1] by considering volume change and the thermal excitation of lattice vibrations, but is too low by a factor of 4 to agree with the optical measurements.[7] Two possibilities should be considered in connection with this discrepancy: (1) $\partial E_G/\partial T$ would have a larger negative value if $m_e m_h$ is less than m_0^2; and (2) the value of $\partial E_G/\partial T$ may be a function of temperature. However, since the R and σ data indicate that $\partial E_G/\partial T$ is constant between 500°K and 850°K, and the optical data indicate a constant value, four times larger, between 80°K and 300°K, it is not likely that one value changes to the other in the intervening temperature range; this point will be checked by extending the optical measurements to high temperatures.

* Assisted by Signal Corps Contract.
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Emission of Neutral Radiation in Cosmic-Ray Stars

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July 12, 1950

IN a search for electron pairs associated with meson showers in photographic emulsions we have so far obtained one fairly definite case of an identified electron pair associated with a 43-pronged star. We also find numerous electron pairs not obviously associated with stars,[1,2] with a fairly wide distribution in energy around several hundred Mev.

Figure 1 shows a photo-micrograph of the event, found in Ilford G5 emulsion (300μ) developed to make minimum ionization tracks particularly visible. The pair originates 120μ from the star center, inside a wide angle cone of about 15 shower particles. The electrons were identified by grain counting and multiple