between these signals can be used as a gate to eliminate completely all lines except pair lines.

The results given in Table I show that NaI(Tl) gives a linear response of pulse height *vs.* energy for electrons up to and including 2.76 Mev.

* This work received partial support from the U. S. Army Signal Corps and the joint program of the ONR and AEC.
[1] J. A. McIntyre and R. Hofstadter, Phys. Rev. **78**, 617 (1950).
[2] In a recent private communication Dr. R. W. Pringle has also reported observing pair lines.
[3] The "photo-line" probably has the full energy of the gamma-ray since the x-ray emitted by iodine is probably degraded and absorbed in the crystal.
[4] S. A. E. Johannsen, Nature **165**, 396 (1950).
[5] R. Hofstadter and J. A. McIntyre, Phys. Rev. **78**, 619 (1950).

## Some Characteristics of the 11-Day Neodymium (147)

C. E. MANDEVILLE AND E. SHAPIRO
*Bartol Research Foundation of The Franklin Institute,* Swarthmore, Pennsylvania*
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THE radiations of the 11-day neodymium (147) have been previously investigated[1-3] and the results obtained have been varied in character. In order to reinvestigate this activity, a quantity of exceptionally pure $Nd_2O_3$ prepared in ion exchange columns at the Institute for Atomic Research, Iowa State College, was irradiated by slow neutrons in the Oak Ridge pile.

Absorption curves in aluminum gave evidence of two beta-ray spectra having end points at 0.17 and 0.78 Mev. The intensity ratio is 1:2.

When the gamma-rays of $Nd^{147}$ were absorbed in lead, components at 35 kev and 0.58 Mev were resolved. The gamma-rays were also absorbed in aluminum, and the half-value thickness of the softer component was found to be 0.33 cm, again indicating a quantum energy[4] of 35 kev. In order to ascertain more positively the nature of the soft quanta emitted in the decay of $Nd^{147}$, critical absorption measurements were carried out using as absorbers solutions of KI, $BaCl_2$, and $LaCl_3$. The absorption in barium and iodine was pronounced as compared with that in lanthanum, an indication that the soft quantum is the *K*-line of promethium. These critical absorption measurements are considered evidence that internal conversion takes place in the de-excitation of $*Pm^{147}$.

The beta-gamma-coincidence rate of $Nd^{147}$ was measured as a function of aluminum absorber thickness before the beta-ray counter as shown in Fig. 1. The shape of the curve substantiates the previous conclusion that the beta-ray spectrum is complex. Since the gamma-ray counter of the beta-gamma-coincidence counting arrangement had been calibrated by the beta-gamma-coincidence rate of $Sc^{46}$, the curve of Fig. 1 could also be interpreted as showing that the inner beta-ray group at 0.17 Mev is coincident with the 0.58-Mev gamma-ray and that the harder beta-ray spectrum is coincident, on the average, with about 0.10 Mev of unconverted gamma-radiation.

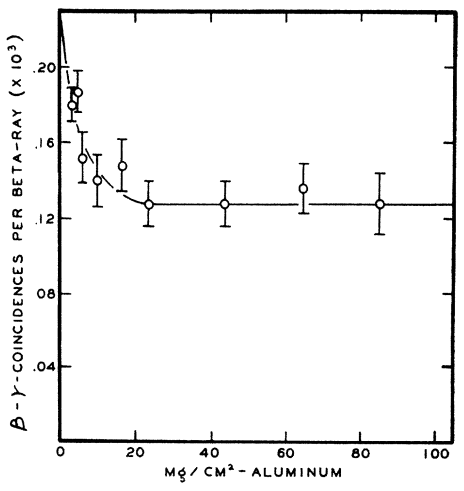


FIG. 1. The beta-gamma-coincidence rate of $Nd^{147}$ as a function of the surface density of aluminum placed before the beta-ray counter. From this curve, it is concluded that both beta-ray spectra are coupled with unconverted quantum radiation.

A search for beta-beta-coincidences yielded no effect. The combined wall thickness and air path of each beta-ray counter was about 6 mg/cm². Soft conversion electrons having a range shorter than this amount would not have been detected. Since the beta-gamma-coincidence data do indicate quanta in coincidence with the harder beta-ray spectrum, and since the x-rays of promethium are very intense, it is concluded that each beta-ray of $Nd^{147}$ is followed by one or more heavily converted gamma-rays in cascade, each one of which has an energy of 0.1 Mev or less. The absence of beta-beta-coincidences does show that the gamma-ray at 0.58 Mev is not appreciably converted.

No gamma-gamma-coincidences were detected in $Nd^{147}$. Whether this can be explained by excessive internal conversion of the soft cascade gamma-rays or by the low quantum efficiency of the counters for soft gamma-rays is not certain.

* Assisted by the joint program of the ONR and AEC.
[1] Marinsky, Glendenin, and Coryell, J. Am. Chem. Soc. **69**, 2781 (1947).
[2] C. O. Muehlhause, Plutonium Project Report CO-3750, 48 (January, 1947), quoted by G. T. Seaborg and I. Perlman, Rev. Mod. Phys. **20**, 585 (1948).
[3] Cork, Shreffler, and Fowler, Phys. Rev. **74**, 240 (1948).
[4] In a previous report C. E. Mandeville, Phys. Rev. **78**, 319 (1950), it was incorrectly stated that the x-rays are fourteen times more intense than the gamma-ray at 0.58 Mev. This estimate was based on the erroneous assumption that the quantum efficiency of the counter was linear with energy even at very low energies. The absorption data were obtained with the use of a counter equipped with a copper cathode so that a high quantum efficiency is developed in the x-ray region owing to the sharp rise in the value of the photoelectric absorption coefficient. The intensity of the x-rays relative to the other quantum radiations is thus exaggerated.

## Properties of Single Crystals of Nickel Ferrite

J. K. GALT, B. T. MATTHIAS, AND J. P. REMEIKA
*Bell Telephone Laboratories, Murray Hill, New Jersey*
May 25, 1950

WE have succeeded in growing single crystals of nickel ferrite ($NiFe_2O_4$) and in determining several of their properties by measurements on small samples.

We find that NiO and $Fe_2O_3$ and $NiFe_2O_4$ dissolve in borax, and that at sufficiently high concentrations a precipitate forms. The data of Snoek[1] indicate that $NiFe_2O_4$ is in equilibrium with this system of compounds above about 1250°C, and we have therefore worked above this temperature. Our crystals are prepared as follows. A mixture of 16 to 17 g of borax glass (sodium tetra-borate fused and ground), 6.4 g $Fe_2O_3$, and 3.0 g NiO is heated in a platinum crucible to 1330°C and held there for 10 to 12 hr. It is then cooled at about 2°/hr. for 25 to 40 hr., and the furnace is then turned off completely. Crystals up to 2 mm on a side are found in the charge, although some are not structurally solid. Chemical analysis of the crystals confirms the formula $NiFe_2O_4$. The Ni and Fe proportions are within 0.1 percent of the values given by this formula, and impurity content is less than 0.5 percent.

We have measured the dielectric constant of these crystals using a capacitance bridge.[2] We find that $\epsilon=19$ at $-185$ to 195°C. Because of the high conductivity of the material, this value is only accurate to $\pm 20$ percent and above this temperature satisfactory measurements were impossible. We also measured $\epsilon$ in a polycrystalline (ceramic) sample of nickel ferrite at $-185$ to $-195$°C and found $\epsilon=21$.

Saturation magnetization has been measured on a small crystal to an accuracy of about 10 percent by comparison with the deflection due to a small sample of iron in a hysteresis loop tracer[3]

and found to be 265 c.g.s. units. This is in agreement with the data of Guillaud and Roux[4] and in fair agreement with the value calculated using the picture developed by Néel.[5]

We have also measured the first-order crystalline magnetic anisotropy constant, $K_1$. This was done by measuring from hysteresis loops of a small crystal of known volume the difference in magnetization energies $\int HdM$ when the sample was magnetized along the (100) and the (111) directions. A spherical sample was used, so that the demagnetizing field was the same in all directions. The sample diameter was 0.10 cm. The value of $K_1$ obtained in this way is less accurate than that obtained from ferromagnetic resonance measurements,[6] but it is probably good to within 10 percent. We find that $K_1=-6.2\times10^4$ ergs/cc at room temperature and $K_1=-8.7\times10^4$ ergs/cc at $-190$°C.

Finally, measurements of complex initial permeability $(\mu'-j\mu'')$ have been made on two extremely small circular rings of square cross section cut so that the plane of the rings was the (111) crystal plane. Their dimensions were approximately as follows: outside diameters 0.1 cm, inside diameters 0.025 cm, thickness 0.04 cm. Measurements were obtained by making each ring the core of a solenoid and measuring the impedance of the solenoids on a radiofrequency Maxwell-type inductance bridge. A plot of the data obtained on the first ring is shown in Fig. 1. The second

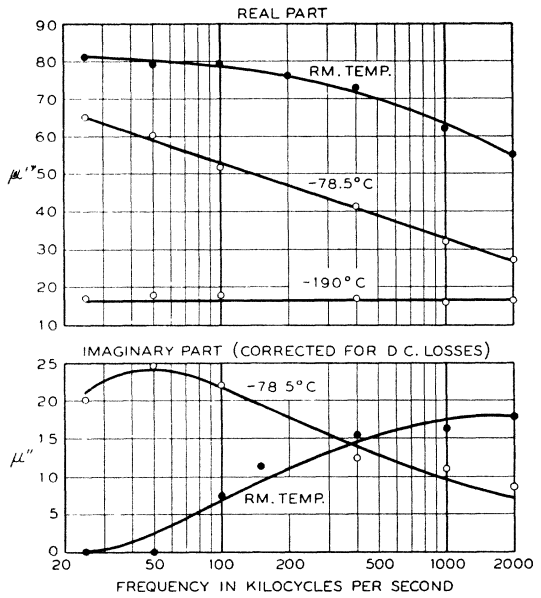


FIG. 1. Permeability *vs.* frequency and temperature of $NiFe_2O_4$ ring in (111) plane.

ring gave similar results. No measurable losses occurred at $-190$°C, so $\mu''$ is not given for that temperature. The resistance as measured was corrected for the resistance of the solenoid wire before $\mu''$ was calculated. The inductance due to the loop formed by the lead to the bridge terminals was also corrected for as well as possible before $\mu'$ was calculated from the measured inductance. It is felt, however, that this latter correction may have been inadequate by enough to reduce all values of $\mu'$ by about 10. This would have no effect on the relative values of $\mu'$, which we feel are more accurate than this, but it makes it possible to account for the value of $\mu'$ at $-190$°C in terms of the rotation of magnetization against crystal anisotropy.

It seems quite clear from Fig. 1 that a relaxation phenomenon is occurring, and since the permeabilities at temperatures above $-190$°C are much higher than those to be expected from the rotation of magnetization against crystalline anisotropy, the relaxation must be connected with domain wall motion. The sharp temperature dependence of the relaxation time suggests that the mechanism involves an activation energy, but we do not at present know the nature of the mechanism.

The authors wish to express their gratitude to W. L. Bond, C. D. Owens, and H. G. Hopper for technical assistance, and to Dr. C. Kittel for helpful discussions.

[1] J. L. Snoek, Physica **3**, 463 (1936), Fig. 7.
[2] W. D. Voelker, Bell Lab. Record **20**, 133 (1942).
[3] The hysteresis loop tracer used for this measurement was of the same general design as that of Wiegand and Hansen, Trans. A.I.E.E. **66**, 119 (1947). The samples used were of the order of 1 mg in weight.
[4] C. Guillaud and M. Roux, Comptes Rendus **229**, 1133 (1949).
[5] L. Néel, Ann. de physique **3**, 137 (1948).
[6] Yager, Galt, Merritt, Wood, and Matthias, Phys. Rev. **79**, 214 (1950). See also a paper to be published later.

## Gamma-Rays from Po—Be Neutron Source and the Excited State of $C^{12}$

P. R. BELL AND W. H. JORDAN
*Oak Ridge National Laboratory, Oak Ridge, Tennessee*
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A NUMBER of gamma-rays have been reported from the $Be^9(\alpha,n)C^{12}$ reaction produced by the $\alpha$-particles from polonium.[1–3] The recent report by Terrell shows only one gamma-ray at 4.3 Mev in the range 2 to 10 Mev. His measurements were made by a magnetic pair spectrometer. The gamma-ray[4] comes from the excited state of $C^{12}$. Our measurement of this gamma-ray gives the value $4.44\pm0.03$ Mev and agrees well in energy with that reported by Bradford and Bennett[5] at 4.44 or 4.46 Mev. Their value was obtained by measuring the neutrons produced by mono-energetic alpha-particles.

We have used a scintillation spectrometer with a sodium iodide, thallium phosphor to measure the gamma-rays from a 5-curie Po—Be source. The crystal was shielded from the source neutrons by paraffin and boron. The energy calibration was accomplished by using the 2.62-Mev gamma-ray of ThC″ from natural thorium and the 0.661-Mev gamma-ray of $Cs^{137}$.

Figure 1 shows the pulse distribution in the energy range from zero to 4.6 Mev. In NaI, pair production and photoelectric peaks are quite prominent. The three peaks at 3.44, 3.94, and 4.42 Mev are due to a single gamma-ray of $4.44\pm0.03$ Mev. The peak of pulses at 4.42 Mev is produced by photoelectric effect with capture of the x-rays emitted from the iodine atom in which it occurs and by pair formation where both members of the pair are stopped and the annihilation radiation from the positron is completely absorbed, giving the full energy of the gamma-ray. The peak at 3.44 Mev is produced by stopping a pair with complete

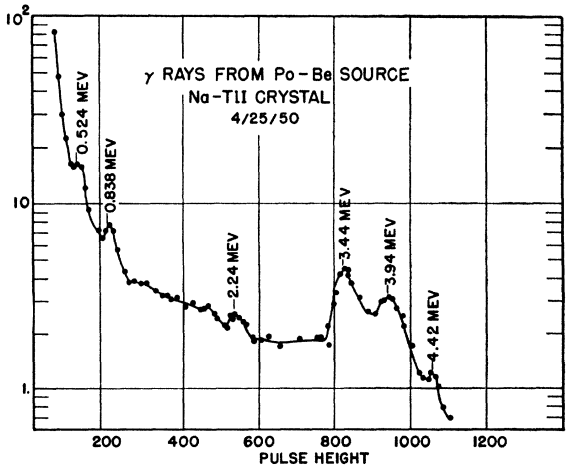


FIG. 1. Pulse distribution produced in the scintillation spectrometer by the gamma-rays of a Po-Be neutron source.