# Letters to the Editor

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## On Charge Independence and High Energy Scattering*

ROBERT JASTROW
*Institute for Advanced Study, Princeton, New Jersey*
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THE Berkeley experiments on $p-p$ scattering at 345 Mev indicate a roughly isotropic cross section between 20° and 90° with a mean magnitude of approximately 4 millibarns/steradian. This is in strong contrast with the results to be expected from a central attractive potential determined by the low energy scattering,[1] from which one obtains at 345 Mev a cross section which arises from 0.2 mb at 90°, to 12 mb at 0°. A qualitative difference is also to be noted between the $p-p$ scattering and the strongly anisotropic high energy $n-p$ scattering.[2]

We wish to show that a charge-independent static[3] potential is not excluded by these results. We assume for this purpose an interaction consisting of a strong short-range repulsion surrounded by an attractive well.[4] The combination is fitted to the low energy scattering. The attractive field is perhaps to be associated with the $\pi$-meson and the short-range repulsive field with a heavier particle.

Considering first $p-p$ scattering at high energies, the repulsive core has the following effect: at energies comparable with or greater than the depth of the surrounding well the effect of the core will dominate in the $S$ state and the sign of the $^1S$ phase shift will change in this energy region from positive to negative. The $D$ state will, at energies of a few hundred Mev, still be affected only by the outer or attractive region of the potential and the $D$ phase shift will be positive. The difference in sign between the $^1S$ and $^1D$ phases causes the $S-D$ interference term in the differential cross section to be positive at 90° and negative at 0°, thereby reducing the anisotropy obtained without the core.

The following potential is used, in which for convenience of calculation the core is represented by a hard sphere and the attraction by an exponential well:

$$V=\infty,\ r<a,$$
$$V=V_0[(\alpha+\beta\sigma_1\cdot\sigma_2)\exp[-(r-a)/R]+\gamma S_{12}\exp(-r/R_{\text{tensor}})];\quad r>a \qquad (1)$$
$$a=0.6\times10^{-13}\text{ cm},\quad R=0.4\times10^{-13}\text{ cm},\quad R_{\text{tensor}}=1.0\times10^{-13}\text{ cm},$$
$$V_0=100\text{ Mev},\quad \alpha=2.18,\quad \beta=-0.52,\quad \gamma=0.65.$$

The strength of the tensor forces in (1) is of the order of that required by the deuteron constants. The scattering at 345 Mev is computed exactly for the central forces and in Born approximation for the tensor forces, neglecting central-tensor interference. The resultant cross section is shown in curve C of Fig. 1, as well as the cross sections computed under the same conditions at 32 and 250 Mev (curves A and B). In curve C the scattering at 20° is 75 percent greater than the mean magnitude of the cross section between 30° and 90°, in contradiction with the experimental distribution. By using a more complicated potential the forward scattering may be substantially reduced. However, in view of the neglect of possible non-static forces an emphasis on precision of fit is perhaps unwarranted in comparison with the importance of simplicity in the interaction.

In treating the $n-p$ scattering we assume that in the charge-antisymmetric states ($^3S$, $^1P$, $^3D$, $^1F$, $\cdots$) one has the interaction of Christian and Hart.[2] These states do not enter into the $p-p$ scattering, which is, therefore, unchanged by this assumption. In this way we can estimate the contribution from triplet states of even $L$ by using the results of Christian and Hart. The singlet contribution is one-fourth of the corresponding $p-p$ cross section as given in Fig. 1. The result is: $\sigma_{np}(90°)=0.8$ mb; $\sigma_{np}(180°)=9.7$ mb. The effect of the core does not destroy the anisotropy of the $n-p$ cross section.

It is seen thus that the introduction of a short-range repulsive force permits one to reconcile the qualitative aspects of the $n-p$ and $p-p$ scattering results with the preservation of charge independence. The arbitrary nature of the particular form of interaction employed should, however, be emphasized, as well as the fact that this result may be obtained from other types of interactions.

The influence of the core on nuclear saturation may be expected to be appreciable because of the zero-point energy arising from the exclusion of each nucleon from the interiors of the other nucleons in a nucleus. This problem is under investigation.

A more detailed account of the work is in preparation.

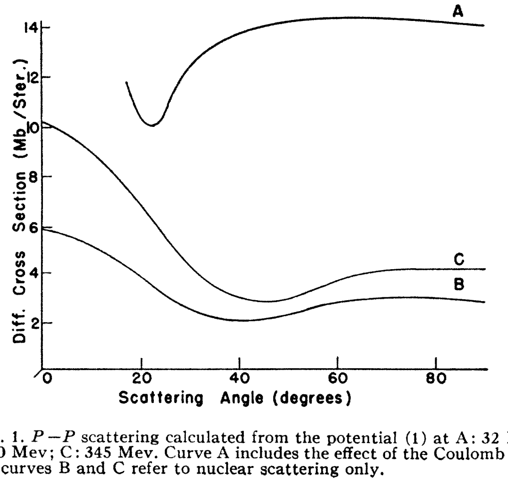


FIG. 1. $P-P$ scattering calculated from the potential (1) at A: 32 Mev; B: 250 Mev; C: 345 Mev. Curve A includes the effect of the Coulomb field, while curves B and C refer to nuclear scattering only.

* This research was supported by an AEC grant to the Institute for Advanced Study.

1 R. S. Christian and H. P. Noyes, Phys. Rev. **79**, 85 (1950).
2 R. S. Christian and E. W. Hart, Phys. Rev. **77**, 441 (1950).
3 A simple velocity dependence, the spin-orbit interaction, has been investigated by K. M. Case and A. Pais, Phys. Rev. **79**, 185 (1950), who conclude that it may be possible by means of this interaction to represent the $n-p$ and $p-p$ scattering qualitatively on a charge-independent basis. See also Blanchard, Avery, and Sachs, Phys. Rev. **78**, 292 (1950).
4 A similar type of interaction has been considered by N. M. Kroll in connection with $p-p$ scattering, and we are indebted to him for interesting and useful criticism. P. O. Olsson has examined the possibility of introducing a repulsion into the $n-p$ potential, as have also G. Parzen and L. Schiff, Phys. Rev. **74**, 1564 (1948).

## Gamma-Ray Measurements with NaI(Tl) Crystals*

R. HOFSTADTER AND J. A. MCINTYRE
*Palmer Physical Laboratory, Princeton University, Princeton, New Jersey*
May 29, 1950

IT has recently been shown[1] by an example with $Co^{60}$ gamma-rays that relatively sharp lines appear in the pulse-height distributions of NaI(Tl) scintillations. These lines, giving directly the full finergy of the gamma-rays, have been interpreted in terms of a photoelectric component (in iodine of NaI) as well as a component arising from capture of all scattered and recoil products of the original gamma-ray in the NaI(Tl) crystal. This method can be used to measure gamma-ray energies (as well as intensities) and proves to be sensitive since the energies are given by sharp maxima of pulse distributions. At higher energies, where $E>2mc^2$, the pair production process becomes important. The purpose of this letter is to extend the method of measurement to the energy range where "pair lines" are observed.[2]

Figure 1 shows the results obtained with $Na^{24}$ (1.38 and 2.76 Mev) when the gamma-source (~1 mC) is collimated so that a narrow (1° divergence) bundle of rays travels through the middle of the NaI(Tl) crystal. Figure 2 shows a similar spectrum for a weak source in an uncollimated arrangement. About two hours of running time were required to obtain the data of Fig. 1 and about one hour for those of Fig. 2. Calibration data in Fig. 1 show the two $Co^{60}$ "photoelectric" peaks at 1.17 and 1.33 Mev. The observed peaks in $Na^{24}$ have been classified as to origin as indicated in Fig. 1. A tabulation of the corresponding pulse heights is given in Table I.

The constancy of the ratio in column 4 shows that the pulse heights are proportional to energy and supports the assignment given in Fig. 1. The shape of the peaks is also consistent with this assignment, for the photoelectric and pair peaks should be symmetrical and sharp while the Compton distributions are broad, unsymmetrical, and have an edge on the high energy side. The pair peak for the 1.38-Mev line which should occur at 0.36 Mev is too weak to be observed.

TABLE I. Pulse height *vs.* energy relation.

| 1<br>Peak | 2<br>Pulse height<br>(volts) | 3<br>Energy<br>(Mev) | 4<br>Ratio<br>pulse height/energy |
|---|---|---|---|
| I ($Na^{24}$) | 34.5[a] | —— | —— |
| II ($Na^{24}$) | 43.5±0.5 | 1.38 | 3.15 |
| III ($Na^{24}$) | 55.0±0.5 | 1.74 | 3.15 |
| IV ($Na^{24}$) | 75.0[a] | —— | —— |
| V ($Na^{24}$) | 88.0±0.5 | 2.76 | 3.18 |
| VI ($Co^{60}$) | 37.0±0.5 | 1.17 | 3.16 |
| VII ($Co^{60}$) | 42.5±0.5 | 1.33 | 3.19 |

[a] These values do not give the positions of the Compton edges but are shifted by the photo-multiplier statistics to slightly lower values.

The general method made clear by Figs. 1 and 2 is based on determining gamma-ray energies by looking for associated triads consisting of two sharp lines separated by a broad peaked Compton distribution. The energy relations between these members of the triad are: highest energy peak[3] "photo-line" ($E_{ph}$), lowest energy peak "pair line" ($E_{pair}=E_{ph}-1.02$ Mev), and in between the Compton peak ($E_c$) near $E_{ph}-0.25$ Mev. At reasonably high energies $E_{pair}$ and $E_c$ predominate. At low energies $E_c$ and $E_{ph}$ predominate.

These results are not in agreement with those recently reported by Johannsen[4] with $Na^{24}$ and NaI(Tl), since Johannsen did not observe pair lines. We have observed less resolution, apparently like Johannsen's, by using a large crystal.[1]

By using a two-crystal arrangement in coincidence[5] the two Compton lines appear at 34.5 and 77.5 volts (Fig. 3). The presence of the third "pair line" at 54 volts is caused by one of the two annihilation quanta being captured in the detector gate crystal. The appearance of the pair line suggests a modification of our two-crystal spectrometer at high energies. If the two annihilation quanta are captured in two separate crystals on opposite sides of the center crystal (struck by the gamma-rays), a coincidence

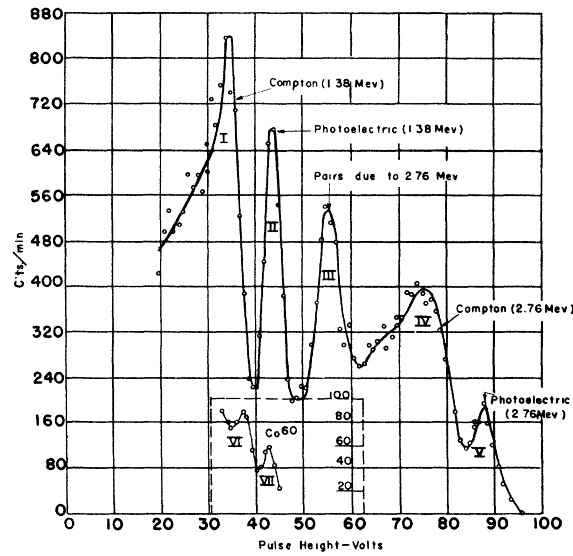


FIG. 1. $Na^{24}$ collimated.

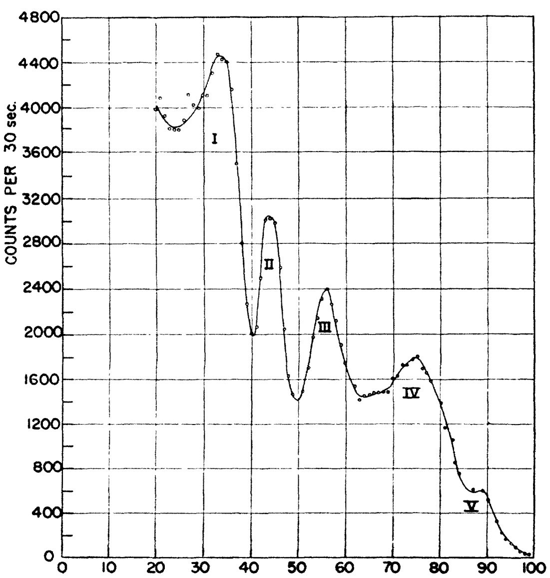


FIG. 2. $Na^{24}$ uncollimated.

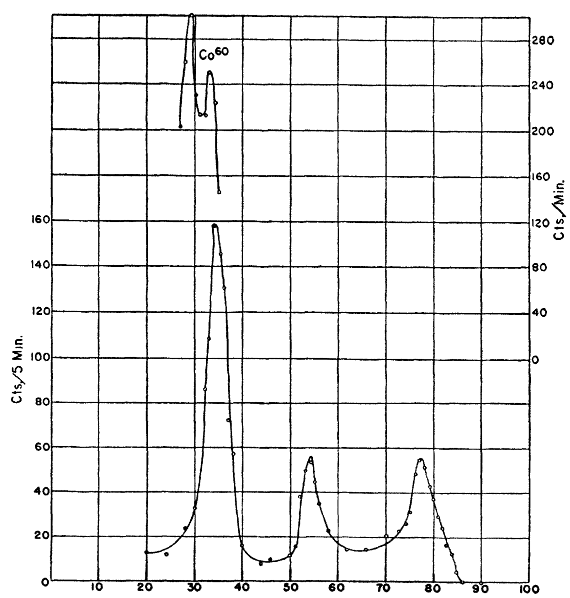


FIG. 3. $Na^{24}$ two-crystal coincidence method.

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*
June 7, 1950

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.

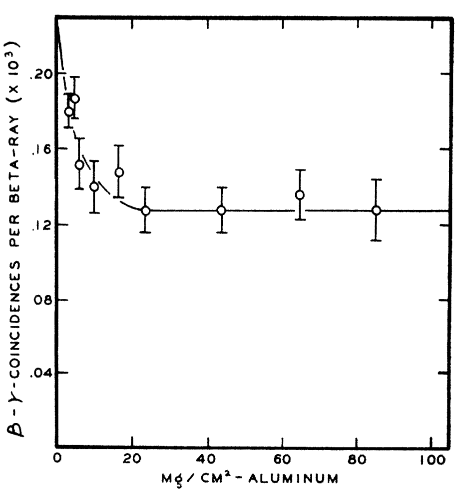


FIG. 1. The beta-gamma-coincidence rate of $Nd^{147}$ as a function of the surface density of aluminum placed before the beta-ray counter. From this curve, it is concluded that both beta-ray spectra are coupled with unconverted quantum radiation.

A search for beta-beta-coincidences yielded no effect. The combined wall thickness and air path of each beta-ray counter was about 6 $mg/cm^2$. 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]