TABLE I. Spins and magnetic moments of nuclei differing by two neutrons.

Nucleus	I	μ	Nucleus	I	μ
$_{17}Cl^{35}$	3/2	0.82103	$_{47}Ag^{107}$	1/2	−0.084
$_{17}Cl^{37}$	3/2	0.681	$_{47}Ag^{109}$	1/2	−0.159
$_{19}K^{39}$	3/2	0.391	$_{48}Cd^{111}$	1/2	−0.595
$_{19}K^{41}$	3/2	0.215	$_{48}Cd^{113}$	1/2	−0.623
$_{29}Cu^{63}$	3/2	2.2233	$_{49}In^{113}$	9/2	5.02
$_{29}Cu^{65}$	3/2	2.3817	$_{49}In^{115}$	9/2	5.52
$_{31}Ga^{69}$	3/2	2.016	$_{50}Sn^{115}$	1/2	−0.89
$_{31}Ga^{71}$	3/2	2.561	$_{50}Sn^{117}$	1/2	−1.000
$_{35}Br^{79}$	3/2	2.108	$_{50}Sn^{119}$	1/2	−1.0465
$_{35}Br^{81}$	3/2	2.2668	$_{51}Sb^{121}$	5/2	3.7
$_{37}Rb^{85}$	5/2	1.3515	$_{51}Sb^{123}$	7/2	2.8
$_{37}Rb^{87}$	3/2	2.7471	$_{54}Xe^{129}$	1/2	−0.9
			$_{54}Xe^{131}$	3/2	−0.8

if, however, the odd particle were required to remain on the edge or the outside of the main body of the nucleus, the increase in nuclear radius resulting from the addition of the two neutrons would then favor orbits with higher angular momentum, as is observed for $Z<20$ and >50. These qualitative requirements on the orbits seem to be somewhat more in accord with the shell scheme of Nordheim than with those of either Feenberg and Hammack or of Mayer.[3]

Although their low natural abundances would probably make their measurement difficult, it would be desirable to know the magnetic moments of the two pairs $_{22}Ti^{47,49}$ and $_{52}Te^{123,125}$ because of their proximity to the proton shells in question.

I wish to thank Dr. J. S. Smart for several interesting discussions.

[1] M. G. Mayer, Phys. Rev. **74**, 235 (1948); **75**, 1969 (1949); E. Feenberg and K. C. Hammack, Phys. Rev. **75**, 1877 (1949); L. W. Nordheim, Phys. Rev. **75**, 1894 (1949).
[2] Data taken from a compilation by W. G. Proctor.
[3] Feenberg, Hammack, and Nordheim, Phys. Rev. **75**, 1968 (1949).

Pair Production in the Field of the Electron by X-Rays from a 100-Mev Betatron*

E. R. GAERTTNER AND M. L. YEATER
Research Laboratory, General Electric Company, Schenectady, New York
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A STUDY has been made of positron-electron pair production in the field of the electron, in air, by x-rays from a 100-Mev betatron. The x-rays are passed through a 2-mil aluminum window into a cloud chamber[1] filled with air and saturated water and alcohol vapor at one atmosphere pressure. The beam is limited to a cross section of $\frac{1}{8}\times\frac{3}{4}$ in. and cleared of secondary electrons by a system of lead shields and permanent magnets. A pulsed magnetic field of 1700 gauss is provided for the cloud chamber. The energy of the pairs and the faster triplet[2] recoils is determined by magnetic deflection, and the energy of the slower recoils is measured by their range, down to about 10 kev (2 mm).[3]

The data have been divided into two groups according to the energy of the pairs. These groups contain, respectively, those pairs and triplets for which the primary x-ray energy lies in the range 5 to 20 Mev, and those for the range 20 to 100 Mev. For each range we have counted the number of triplets and the corresponding number of pairs. The triplet to pair ratios so obtained are averages over the continuous x-ray spectrum of the betatron.

The number of events counted as pairs is 315 between 5 and 20 Mev; the number between 20 and 100 Mev is 788. The corresponding number of observed triplets is 27 between 5 and 20 Mev, and 63 between 20 and 100 Mev. There appears to be a preponderance of recoils with momentum in the neighborhood of mc or less. A few have larger momenta, extending to about 6 mc.

The ratio of the average pair to triplet cross sections can be computed from our data for each of these energy intervals if the number of undetected triplets can be evaluated. Some recoil electrons are unobserved because their range is short, and others are lost because their orientation in space is such that the projection of the track in the horizontal plane is too short for detection. If the projected length of the recoil is less than 1 mm, we expect it to be unnoticed. If the space length of a recoil is less than 2 mm, corresponding to an energy of 10 kev, the identification of the event as a triplet is not positive and it is counted as a pair. The ratio of the observed number to the total number of triplets is by definition our detection efficiency. This can be written as $\eta=\eta_1\eta_2$, where η_1 is the geometrical efficiency and η_2 is the fraction of the triplets for which the recoil energy is equal to or greater than 10 kev. The calculated average value of η_1 is 85 percent. The efficiency η_2 has been calculated by numerical integration of Bethe's equations[4] for an unscreened nucleus of unit charge. For our detection limit, η_2 varies from 98 percent at 20 Mev to 75 percent at 100 Mev, with an average of 87 percent in the range 20 to 100 Mev and nearly 100 percent for the range 5 to 20 Mev.

From our data and these efficiencies we have calculated ratios of the average triplet to pair cross sections for our air-vapor mixture (effective atomic number $Z=7.32$). Multiplying these ratios by Z, we obtain average values for the quantity A in the expression for the dependence on Z of the total pair plus triplet cross section, $\sigma_p\propto Z(Z+A)$. We find $A=0.75$ for the energy range 5 to 20 Mev, and $A=0.8$ for the range 20 to 100 Mev. The estimated errors are ± 25 and ± 20 percent, respectively, based on the number of events counted, the uncertainty in the identification of a few of the triplets, and the uncertainty in our calculation of the efficiencies.

Our result for the energy range 5 to 20 Mev (mean energy 11 Mev) may be compared with the theoretical results of Borsellino.[5] From his data we derive an average value of $A=0.61$ for this interval. For x-ray energies in the range 20 to 100 Mev, our value of A may be compared with the theoretical results of Borsellino and Wheeler and Lamb.[6] Up to an energy of 50 Mev, Wheeler and Lamb's data yield $A=1$, since screening can be neglected in this case; at 100 Mev their value is only slightly greater than 1. Borsellino has shown, however, that the cross section for pair production in the field of the electron is less than in the field of the proton.[7] The difference is 15 percent at 50 Mev and increases with decreasing quantum energy. Although we do not have the corresponding data for the interval 50 to 100 Mev, it appears that the theoretical A lies between 0.85 and 1.05 in this region. With this assumption we have calculated limiting theoretical values for A, averaged over the continuous x-ray spectrum from 20 to 100 Mev. The result is $0.80<A_{\text{theor}}<0.86$.

We wish to thank Dr. E. E. Charlton and the betatron group for their cooperation. We are grateful to Professor H. A. Bethe and Dr. H. Hurwitz for discussions of the theoretical aspects of the problem.

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[1] This cloud chamber is described by the authors in Rev. Sci. Inst. **20**, 588 (1949).
[2] "Triplet" is defined as a pair with a visible electron recoil which indicates the pair to have been formed in the field of the recoiling electron. The calculated probability of a spurious triplet, resulting from a coincidence between a pair and a stray electron, is one in 7500 pairs.
[3] N. N. Das Gupta and S. K. Ghosh, Rev. Mod. Phys. **18**, 280 (1946).
[4] H. Bethe, Proc. Camb. Phil. Soc. **30**, 524 (1934). In the neighborhood of 50 Mev Bethe's equations for the unscreened nucleus of unit charge give a result identical with that of Wheeler and Lamb for the electronic case. See J. Wheeler and W. Lamb, Phys. Rev. **55**, 858 (1939).
[5] A. Borsellino, Helv. Phys. Acta **20**, 136 (1947).
[6] J. Wheeler and W. Lamb, Phys. Rev. **55**, 858 (1939).
[7] Professor H. A. Bethe has pointed out to us that the values of A derived from Wheeler and Lamb should be reduced in accordance with the results of Borsellino.

Scintillation Counting with Solutions*

HARTMUT KALLMANN
Department of Physics, New York University, New York, New York
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IT is a drawback of scintillation counting with crystals that large-sized crystals are found not to be very transparent. They exhibit a considerable light scattering which gives rise to additional absorption. This drawback could be overcome if instead of crystals one were able to use liquids, which can be applied in large thicknesses without considerable absorption. In the course of the investigation of the fluorescent efficiency of liquid solutions when excited by gamma-radiation and by neutrons, special solutions were used which exhibited a fluorescent efficiency high enough to make them applicable for counting work.

Circuit.—The experimental arrangement used consisted of a multiplier tube of Type 5819. On its light-sensitive top surface a glass or porcelain tube of almost equal diameter was cemented. The glass tube was supplied with a reflecting layer (white paint or metal surface), or it can even be used with transparent walls. The liquid filled this tube and thus contacted the top surface of the multiplier directly. The upper surface of the liquid was covered with a reflecting layer. With the best solutions the following results were obtained.

Gamma-radiation.—With gamma-radiation from a radium source maximum scintillation peaks were obtained which were about five times larger than the maximum noise peaks. This means that these light flashes of maximum intensity released about 30 to 40 primary electrons from the photo-cathode. Also with softer x-ray sources the peaks could easily be detected without using a coincidence arrangement.

Neutron radiation.—With a polonium and beryllium neutron source larger peaks were obtained. The maximum size was about 15 to 20 times larger than the largest noise pulse, corresponding to a primary emission of 100 to 150 electrons per light flash. In the case of neutrons, as well as in that of gamma-radiation, the number of peaks were considerably larger than that obtained with normally available organic crystals.

Alpha-radiation.—Alpha-particles from a polonium source bombarded the surface of a solution of about 1-cm thickness. This means that the alpha-particles hit the surface of the liquid about 1 cm away from the photo-sensitive layer. In this case the alpha-particles gave rise to peaks about five times the size of the maximum noise peaks. Since the alpha-particles have an energy of about five million electron volts their efficiency in producing light emission is about three times smaller than that of gamma-radiation (gamma-radiation of about two million volts gives the same peak height). When the thickness of the solution was increased to about 6 cm the alpha-peak intensity decreased to approximately three times the size of the maximum noise peaks. Since in this case the light flashes are only produced at the upper surface, the solid angle subtended by the light at the photo-cathode is much smaller. A considerable part of the light only hits the photo-cathode after one or even several reflections at the side walls and it is quite probable that a part of the loss in intensity with increasing thickness of solution may be due to losses connected with the reflection at the walls. It may be that in large thicknesses of more than 10 cm a certain amount of absorption in the solution is already taking place.

General considerations.—Similar experiments in glass tubes without a reflecting layer at the walls gave intensities about 25 percent less than those with reflecting walls. This indicates that the walls of the tube partly operate as reflector by total reflection.

When all radiation sources are removed, a certain number of very large peaks were observed which sometimes were larger than 50 times the maximum noise pulse peaks, which means the emission of several hundreds primary electrons from the photo-cathode. These pulses were characteristic of the solution and disappeared when the solution was removed. It is supposed that these large peaks originated in cosmic-ray particles crossing the solution. Their frequency amounted to three peaks per minute which, with a solution of 50-mm thickness, would be a reasonable number of peaks to be induced by cosmic radiation.

Time constants of the solutions.—Very preliminary and rough checks of the time constants of these solutions were made. The electric circuit contained a resistor of 50,000 and in some cases of 10,000 ohms. In these cases the decay time of the observed pulses were those caused by the time constant of the electric circuit. The rise times of the peaks were practically that of the operating amplifier. This means that a very considerable part of the light emission of these solutions takes place within a period of time smaller than 10^{-7} sec.

The solutions.—A variety of solutions were found applicable for counting work. Solutions of toluene and xylene with fluorene, carbazole, phenanthrene, and anthracene prove to be nearly equally successful. Also mixtures of these solutions could be used advantageously. All solutions exhibited a maximum concentration for light efficiency, which in the case of carbazole was as low as 0.2 gram per liter. With phenanthrene the maximum concentration came out to be 8 gram per liter. The light efficiency was also increased when paraffin oil was added to the solution. Another type of equally good fluorescent solution was paraffin oil with dissolved xylene and with the addition of small amounts of anthracene, fluorene, phenanthrene, and carbazole. It is most essential for those experiments to work with pure substances, since very small amounts of contamination give rise to quenching effects. Thus, most of the substances used exhibited their maximum light efficiency only after being purified in our laboratory.

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Nuclear Coupling and Shell Model

GIULIO RACAH
The Hebrew University, Jerusalem, Israel
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IN a recent paper[1] Feenberg examined some general aspects of nuclear structure from the point of view of strong spin-orbit coupling, and we wish to add some remarks to his considerations.

Feenberg considered as a "reasonable supposition" that the statistical weight of the singlet component for states in the antisymmetric j^2 function space attains a maximum at $I=0$. With the aid of Dirac's vector model it is very easy to prove this supposition and also to extend the calculation to the antisymmetrical j^n function space; i.e., to n-like particles in equivalent orbits.

The statistical weight of the singlet component in the coupling of two particles is given by the expectation value of

$$S_{12}=\tfrac{1}{4}-(\mathbf{s}_1\cdot\mathbf{s}_2), \tag{1}$$

and in extreme jj coupling this expectation value is

$$\begin{aligned}\langle S_{12}\rangle_{\text{Av}}&=\tfrac{1}{4}-(\mathbf{s}_1\cdot\mathbf{j}_1)(\mathbf{s}_2\cdot\mathbf{j}_2)(\mathbf{j}_1\cdot\mathbf{j}_2)/[j(j+1)]^2\\&=\tfrac{1}{4}-(\mathbf{j}_1\cdot\mathbf{j}_2)/(2l+1)^2\\&=\tfrac{1}{4}+[2j(j+1)-I(I+1)]/2(2l+1)^2,\end{aligned} \tag{2}$$

and attains therefore a maximum for $I=0$, in agreement with Feenberg's supposition.

For n-like particles in equivalent orbits the weight of the singlet couplings is

$$\langle\Sigma S_{ik}\rangle_{\text{Av}}=\tfrac{1}{8}n(n-1)+[nj(j+1)-I(I+1)]/2(2l+1)^2 \tag{3}$$

and attains a maximum for the minimal I allowed by the exclusion principle.

If now strong Majorana forces coexist with strong spin-orbit forces, the spin I of the ground state of an odd nucleus should equal the j of the uncoupled particle only in the trivial cases of one particle in an empty shell or one hole in a filled shell, and should be $\frac{3}{2}$ in the cases of three particles in an empty shell or three holes in a filled shell, and $\frac{1}{2}$ in any other case.

The situation is different in the space orbital approximation. In this case the weight of the singlet couplings,

$$\Sigma S_{ik}=\tfrac{1}{8}n(n+2)-\tfrac{1}{2}S(S+1), \tag{4}$$

is not a sufficient criterion for determining the lowest state, as it has the same value for all terms with the same S, and the sta-