$$W^{(1/2)} = \frac{e^2}{2c^2}\int_{\omega_1}^{\omega_2} \omega\left[2\cos^2\theta - \frac{\hbar\omega}{cp}(n\cos\theta + 1/\beta)\right]d\omega \qquad (5)$$

for a particle with half-integral spin and

$$W^{(0)} = \frac{e^2}{c^2}\int_{\omega_1}^{\omega_2} \omega\left(\cos^2\theta - \frac{\hbar\omega n}{cp}\cos\theta\right)d\omega \qquad (6)$$

for a particle of zero spin. Here

$$\cos\theta = 1/\beta n + (n\omega\hbar/2pc)(1 - n^{-2}) \qquad (7)$$

(**p** is the initial momentum of the electron, θ is the angle between **p** and the direction of photon emission). The integrations in Eqs. (5) and (6) are taken over the frequency regions for which the inequality $\cos\theta \leq 1$ is satisfied.

The following remarks may be made concerning the derivation of Eqs. (5) and (6): first, the quantum correction is proportional to $\hbar$ as in the case of the transverse field of longitudinally polarized electrons;[9] second, in the case of the longitudinal field there is no specific quantum correction proportional to $\hbar^2$ due to the electron spin in the transverse field. The latter situation leads one to believe that the indicated correction is due to the transverse field rather than the spin of the electron. There is at least one important difference from the case of the transverse field; in the classical analysis of Cerenkov radiation of transverse waves there is no radiation threshold; in the case of longitudinal waves, however, the radiation remains finite at the threshold, even in the classical approximation. Thus, neglecting terms of order $\hbar$ and higher in Eq. (5) we have

$$W^{(1/2)} = W^{(0)} = (e^2/2c^2)(\omega_2^2 - \omega_1^2). \qquad (8)$$

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[1] V. L. Ginzburg, J. Exptl. Theoret. Phys. (U.S.S.R.) **34**, 1593 (1958), Soviet Phys. JETP **7**, 1096 (1958).

[2] S. I. Pekar, J. Exptl. Theoret. Phys. (U.S.S.R.) **33**, 1022 (1957), Soviet Phys. JETP **6**, 785 (1958).

[3] S. I. Pekar, J. Exptl. Theoret. Phys. (U.S.S.R.) **34**, 1176 (1958), Soviet Phys. JETP **7**, 813 (1958).

[4] W. Fock and B. Podolsky, Sow. Phys. **1**, 801 (1932).

[5] D. D. Ivanenko and A. A. Sokolov, Классическая теория поля (Classical Theory of Fields) Gostekhizdat, M.-L., 1951.

[6] A. Sokolov and D. Ivanenko, Квантовая теория поля (Quantum Theory of Fields) Gostekhizdat, M.-L., 1952.

[7] A. A. Sokolov, Dokl. Akad. Nauk SSSR **28**, 415 (1940).

[8] A. A. Sokolov and Yu. M. Loskutov, J. Exptl. Theoret. Phys. (U.S.S.R.) **32**, 630 (1957), Soviet Phys. JETP **5**, 523 (1957).

[9] A. A. Sokolov and Yu. M. Loskutov, J. Exptl. Theoret. Phys. (U.S.S.R.) **34**, 1022 (1958), Soviet Phys. JETP **7**, 706 (1958).

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COULOMB EXCITATION OF NEON

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In studying Coulomb excitation of nuclei one can observe various excitations in the target nucleus. It is also possible to observe excitations in the bombarding particle if the latter exhibits levels for which the Coulomb excitation cross section is large. In most of the work on Coulomb excitation the bombarding particles have been protons or α particles. Inasmuch as H^1 and He^4 do not have suitable levels the effect noted above has not been observed. In certain cases, however, the use of heavy ions as bombarding particles makes it possible to observe the excitation of nuclear excitations in these particles.

The present authors have investigated Coulomb excitation in Ne^{20} and Ne^{22}. The first excited levels are at 1.63 and 1.275 Mev respectively. Coulomb excitation of these levels has still not been studied because the intensity of the γ rays produced when neon is bombarded by protons or α particles is low unless the latter have high energies, i.e., energies comparable with the potential barrier. For this reason the measurements are complicated by background effects. In the usual method, when the element being investigated serves as the target (if a thick gas target is used), it is difficult to measure the beam current. It is probably for this reason that in the work reported in references 1 and 2, concerning an investigation of Coulomb excitation of krypton and xenon, the authors were able to determine only the relative values of the γ yields.

In the present work accelerated neon ions have been used as the bombarding particles. Neutral neon was admitted to the ion source of the cyclotron. The cyclotron was tuned for the different ions (Ne^{20} or Ne^{22}) by varying the magnetic field, keeping the frequency of the accelerating field fixed. The average beam current at the target was 1.5×10^{-8} amp for Ne^{20} and 1.5×10^{-9} amp for Ne^{22} (these figures correspond to the isotropic composition of the neutral neon). The energy of the $Ne^{20 \cdot 4+}$ ions was approximately 23.5 Mev, the energy of the $Ne^{22 \cdot 4+}$ ions was 25.8 Mev. The following materials were used as targets: Be, B, C, Mg, Al, Si, $Mg^{24}O$, $Mg^{25}O$, $Mg^{26}O$ and ScO. Calculations indicate that the γ-ray intensity associated with the Coulomb excitation of Ne^{20} or Ne^{22} falls off rapidly with increasing atomic number of the target. For this reason only light targets were used in the present experiments.

The γ rays were detected with a γ spectrometer in which a NaI(Tl) crystal was used.[3,4] The energy losses of the neon ions in these targets were computed by means of the method proposed by Longchamp[5] and by the range-energy curve for neon ions in lead, plotted by A. Papineau using a method suggested in reference 6.* In the latter case the calculation of stopping power in the element of interest was carried out using the ratio of the specific energy loss in lead (obtained experimentally) to that in the given element for protons with the same velocity as the neon ions. The values of $dE/d\rho x$ obtained by both methods agreed to within 12%.

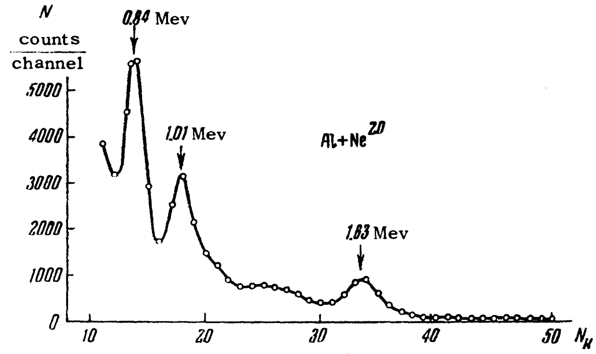

FIG. 1

In Figs. 1 and 2 are shown the spectra of γ rays emitted in the Coulomb excitation of the level characterized by $\Delta E = 1.63$ Mev for Ne^{20} ions and the level characterized by $\Delta E = 1.275$ Mev for Ne^{22} ions. In both cases the target is aluminum. Similar spectra were observed in the bombardment of the other targets. The only exceptions were boron and beryllium. No peak for $E = 1.63$ Mev was observed in bombardment by Ne^{20} ions because of the very strong γ background due to nuclear reactions. In

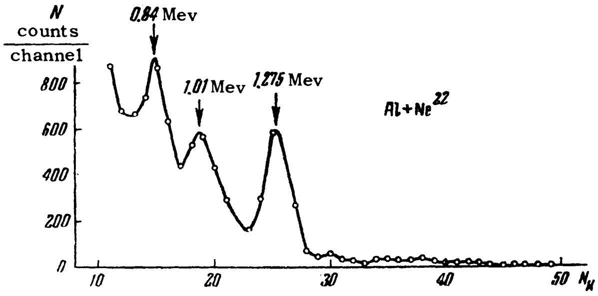

FIG. 2

the bombardment with Ne^{22} there was a well-defined peak for $E = 1.275$ Mev but the calculation of B(E2) gave a value which was considerably higher (in the case of beryllium, a factor of 10) than those obtained with the other targets. This is apparently due to the fact that in the $(Be + Ne^{22})$ and $(B + Ne^{22})$ reactions the collision energy is approximately the same as the value of the Coulomb barrier.

The mean values of B(E2) are $0.041\, e^2 \times 10^{-48}$ cm^4 for the Ne^{20} level characterized by $\Delta E = 1.63$ Mev and $0.025\, e^2 \times 10^{-48}$ cm for the Ne^{22} level characterized by $\Delta E = 1.275$ Mev. The mean life times for these states (τ) are respectively 8.6×10^{-13} sec and 4.8×10^{-12} sec. The indicated value of $\tau(Ne^{20})$ is in good agreement with the value reported in reference 7 in which τ was measured from the Doppler broadening of the γ-line and found to be $(7.6 \pm 3.3) \times 10^{-13}$ sec.

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[1] Heydenburg, Pieper, and Anderson, Phys. Rev. **108**, 106 (1957).

[2] Pieper, Anderson and Heydenburg, Bull. Am. Phys. Soc. **3**, 38 (1958).

[3] Alkhazov, Andreev, Grinberg, and Lemberg, Izv. Akad. Nauk SSSR, Ser. fiz. **20**, 1365 (1956). [Columbia Tech. Transl. **20**, 1249 (1956)].

[4] Alkhazov, Andreev, Erokhina, and Lemberg, J. Exptl. Theoret. Phys. (U.S.S.R.) **33**, 1347 (1957), Soviet Phys. JETP **6**, 1036 (1958).

[5] J. P. Longchamp, J. Phys. et radium, **14**, 89 (1956).

[6] A. Papineau, Compt. rend. **242**, 2933 (1956).

[7] Devons, Manning, and Towle, Proc. Phys. Soc. **A69**, 173 (1956).

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