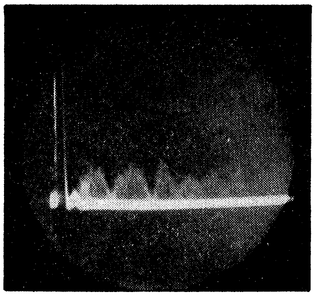

FIG. 2. H_0 in $(1/\sqrt{2},1/\sqrt{2},0)$ direction and equal to 15.5 gauss. Sweep length is 1500 μsec.

for $\theta_0=0$ or π. This corresponds to the condition that H_0 does not cause "mixing" of the $m=\pm\frac{1}{2}$ states so that the $+m$ and $-m$ states form two independent systems. An analogous system in nuclear magnetic resonance is that of two groups of identical nuclei, chemically shifted with respect to one another, but which do not interact with one another.

In order to verify the theory in detail, the Cl^{35} quadrupole resonance in a single crystal of $NaClO_3$ was studied. A distribution of $|\nabla E|$ was artificially set up by introducing a temperature gradient across the sample. Otherwise, the induction signal from the first pulse would still have a large amplitude in the interesting region $(2\tau \lesssim 2\pi/\gamma H_{loc})$, since the natural line width is solely due to internal magnetic fields, causing the echo, which is randomly phased (for a pulsed oscillator) relative to the first induction decay, to flutter.

In applying Eq. (1) to $NaClO_3$, contributions from the four different directions of ∇E in the unit cell must be added. As shown previously,[1] H_0 and H_1 oriented along the (0,0,1) axis is the simplest case since the θ_0's for each of the ∇E's are identical. For this case, Eq. (1) predicts

$$V(2\tau)\propto(5/9)+(4/9)[2\cos(\sqrt{3}\gamma H_0\tau)+\cos^2(\sqrt{3}\gamma H_0\tau)],$$

which explains within experimental error the frequency of the "slow beats" shown in Fig. 1 and, approximately, the amplitudes if the term in square brackets is assumed to decay with a time constant $\approx 2\pi/\gamma H_{loc}$.

The more complicated echo envelope shown in Fig. 2, corresponding to H_0 along the $(1/\sqrt{2},1/\sqrt{2},0)$ axis, is also explained by Eq. (1) which predicts

$$V(2\tau)\propto(5/3)+[\cos(2\gamma H_0\tau)+\tfrac{1}{3}\{2\cos(\sqrt{2}\gamma H_0\tau)+\cos^2(\sqrt{2}\gamma H_0\tau)\}].$$

When a crystalline powder is used, the beat structure also persists for a time $\approx 2\pi/\gamma H_{loc}$, even though the electric field gradients are oriented at random angles to H_0. It is expected that a numerical integration over the complicated angular dependence will illustrate this. Figure 3 shows the slow beat in a crystalline powder of $NaClO_3$. The individual induction signals have a decay time $\approx 2\pi/\gamma H_0$, which is also the period of the slow beat here so that it is unnecessary to induce a temperature gradient in the sample in order to observe the effect. Similar patterns were observed in CH_3CCl_3, $(CH_3)_3CCl$, and $CHCl_3$.

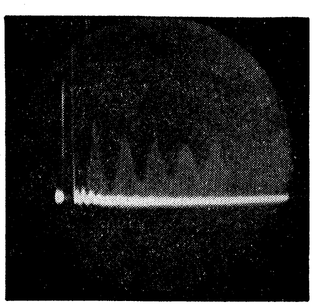

FIG. 3. Crystalline powder of $NaClO_3$. $H_0=15.5$ gauss. Sweep length is 1340 μsec.

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Interference of Rayleigh and Nuclear Thomson Scattering

A. M. CORMACK
Physics Department, University of Cape Town, Rondebosch, Cape Town, South Africa
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THE differential cross sections σ_T and σ_R for elastic scattering of gamma rays by the nucleus (nuclear Thomson scattering), and by the atomic electrons (Rayleigh scattering) have been given and discussed by Moon.[1] Since both of these scattering processes are elastic, interference effects are to be expected, and calculations have been made to determine the effect of this interference on the combined differential cross section for the atom σ_{R+T} for scattering by either the nucleus or by the electrons of the atom.

This combined cross section is given by (see Heitler[2])

$$\sigma_{R+T}(\theta)=\left(\frac{1+\cos^2\theta}{2}\right)\left|\left(\frac{e^2}{mc^2}\right)\int|\psi_e|^2\exp[i(\boldsymbol{\kappa}-\boldsymbol{\kappa}_0)\cdot\mathbf{R}_e]dv_e+\frac{Z^2e^2}{Mc^2}\exp[i(\boldsymbol{\kappa}-\boldsymbol{\kappa}_0)\cdot\mathbf{R}_n]\right|^2, \quad (1)$$

where the angle of scattering is θ, $\boldsymbol{\kappa}_0$ and $\boldsymbol{\kappa}$ are the propagation vectors of the incident and scattered photons, m and M are the masses of the electron and the nucleus, and $\mathbf{R}_n$ and $\mathbf{R}_e$ are vectors to the nucleus and to a typical point of the electron distribution which has the wave function ψ_e. It has been assumed that the wavelength of the radiation is much larger than the dimensions of the nucleus. Taking the square moduli of the two terms separately gives σ_R and σ_T, respectively. The matrix element for the Rayleigh scattering has been evaluated by Franz[3] assuming a Thomas-Fermi atom, and he finds that

$$\int|\psi_e|^2\exp[i(\boldsymbol{\kappa}-\boldsymbol{\kappa}_0)\cdot\mathbf{R}_e]dv_e=\frac{Z}{u}(\pi/2u)^{\frac{1}{2}}, \quad (2)$$

$$u=(5.86/\lambda Z^{\frac{1}{3}})\sin(\theta/2), \quad (3)$$

λ being the wavelength of the radiation in angstroms. Equation (2) is valid for gamma-ray energies of up to a few Mev and for $Z<40$. For $Z>40$, relativity effects become noticeable but only amount to 16 percent for $Z=90$, so (2) will be adequate for the purpose in hand.

If ψ_e is symmetrical about the nucleus and we write $\mathbf{R}_e=\mathbf{R}_n+\mathbf{r}$, then (1) gives

$$\sigma_{R+T}=\sigma_R+\sigma_T+2(\sigma_R\sigma_T)^{\frac{1}{2}}, \quad (4)$$

which represents the classical reinforcement of the two kinds of scattering, in agreement with a remark of Moon. If ψ_e is not symmetrical about the nucleus, a phase term will occur within the modulus signs in (1), and this will give rise to an angle-dependent modification of (4) which represents classical destructive interference effects between the scattering processes. The curves given by Moon for σ_R and σ_T show that they are comparable in magnitude only at large scattering angles, and since, in addition, observations of these types of scattering would have to be made with a biased scintillation counter at large scat-

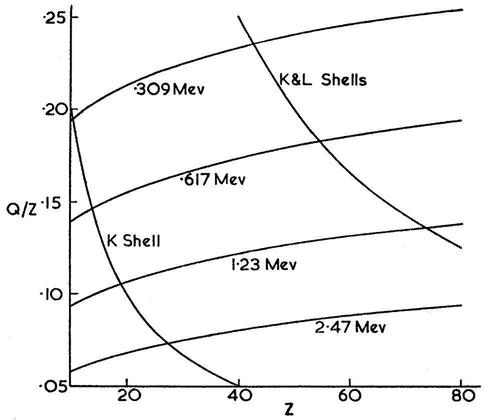

FIG. 1. The charge Q contributing 90 percent of the Rayleigh scattering as a function of the atomic number Z for various gamma-ray energies.

tering angles to eliminate the large background of inelastically scattered Compton gamma rays, it will be sufficient to consider only $\theta\approx 180°$. The fraction of the total number of electrons which contribute a given fraction F^2 of the Rayleigh scattered intensity at 180° was found by solving the equation,

$$\int_0^{r_0}|\psi_e|^2\exp[i(\boldsymbol{\kappa}-\boldsymbol{\kappa}_0)\cdot\mathbf{r}]r^2dr=(FZ/u)(\pi/2u)^{\frac{1}{2}},\qquad(5)$$

numerically for r_0, for $F^2=90$ percent and for various values of λ and Z using the Thomas-Fermi distribution for the atom. The charge contained within the sphere of radius r_0 about the nucleus was calculated and the results are shown in Fig. 1 where the fraction of the number of electrons contributing 90 percent of the Rayleigh scattering is plotted against Z for various values of the energy of the gamma rays. The curves for all values of λ and F satisfying $\lambda/(1-F)^2=$constant will be the same, so that the curves given may be used for values of λ and F other than those shown. For comparison, the fraction of the atomic number represented by the K electrons and the K and L electrons together are also shown as a function of Z.

For destructive interference effects to be observable, appreciable deviations from spherical symmetry will have to occur within the radii containing the charges calculated above, and it will be seen that the most favorable conditions for the occurrence of these deviations from spherical symmetry (due to effects such as molecular binding) are low Z and low gamma ray energy. But the ratio of the Thomson to the Rayleigh cross sections, $\sigma_T/\sigma_R\sim ZE^3$, so that when deviations from spherical are most likely to occur σ_T/σ_R is so small, and in fact σ_R itself is so small, as to preclude the possibility of the observation of any interference effects.

It may therefore be concluded that for all gamma-ray energies and values of Z at which either of the scattering processes may be observed, Eq. (4) gives the correct differential cross section for the atom.

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Decay of the χ Meson

SEIICHI SUEOKA*
Division of Physics, National Research Council, Ottawa, Canada

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RECENTLY many experiments[1] have shown that the χ meson possibly undergoes the following two-body mode of decay, $\chi^\pm\rightarrow\pi^\pm+N^0$, since the secondary π meson very probably has uniform energy. Here N^0 denotes an unknown neutral particle. If for N^0 we take the known neutral particles, we have three possibilities, namely,

$$\begin{aligned}\chi^\pm&\rightarrow\pi^\pm+\gamma; & m_\chi&\sim 945m_e,\\ &\rightarrow\pi^\pm+\pi^0; & m_\chi&\sim1019m_e,\\ &\rightarrow\pi^\pm+\theta^0; & m_\chi&\sim1610m_e.\end{aligned}$$

The only other possibility, $N^0=\nu^0$, is omitted, because then the χ meson would have to be considered to be a fermion. The approximate values of the mass of the χ meson corresponding to each scheme are given above. In the first two cases the mass is very close to that of the τ meson, but in the last the mass seems to differ considerably from that of the τ meson. Because of this experimental fact, a suggestion was put forward at the Cosmic Ray Congress[2] held at Bagnères-de-Bigorre, France (July, 1953) that the χ and κ mesons are possibly identical with the τ meson but have alternative decay modes instead of the usual 3π decay of the τ meson.

Goldhaber[3] has speculated on the possibility of finding a correlation between the various particles by considering the θ^0 meson as the fundamental meson in nucleon-nucleon reactions. As far as the hyperons and τ mesons are concerned, this idea is natural and helpful, and does not lead to any contradictions. Goldhaber brings the χ meson and κ meson into this scheme by assuming the following decay schemes proposed at the above-mentioned Bagnères Congress:

$$\chi\text{ mode: }\tau^\pm\rightarrow\pi^\pm+\begin{cases}\gamma\\ \pi^0\end{cases},$$

$$\kappa\text{ mode: }\tau^\pm\rightarrow\mu^\pm+\nu^0+\begin{cases}\gamma\\ \pi^0\end{cases}.$$

These decay modes are consistent with the usual 3π decay. But here we wish to point out that the identification of $\chi^\pm(\chi^\pm\rightarrow\pi^\pm+\pi^0)$ with $\tau^\pm(\tau^\pm\rightarrow\pi^\pm+\pi^++\pi^-)$ leads to a difficulty from the point of view of the selection rules for the decay modes of bosons based on the principles of charge conjugation and charge symmetry.[4–6] The relevant theorem for our purpose can be stated as follows: the reaction between charged and neutral mesons through a nucleon field is forbidden if the total number of vector and tensor couplings is odd. Further, the conservation of angular momentum and parity leads to the absolute selection rules which are stronger than those mentioned above. Using all these selection rules, we can easily get the permitted kind of meson for various decaying mesons (bosons). Here we consider only the case that τ and χ mesons do not have higher spin than unity and we assume that these mesons are not composite structures but elementary bosons.

Denoting by A, P, and T the decay schemes forbidden by the conservation of angular momentum, the conservation of parity, and the extension of Furry's theorem, respectively, we get the results listed in Table I, which shows the forbiddenness of each decay scheme of τ meson and χ meson for various mesonic properties. Here we assume that the π meson is a pseudoscalar meson.[7] Here S, V, PV, and PS denote, respectively, the scalar, vector, pseudovector, and pseudoscalar meson and s, v, t, pv, and ps denote, respectively, the scalar, vector, tensor, pseudovector and pseudoscalar coupling of the meson with the nucleon field. $\tau_{(0)}$ or $\tau_{(3)}$ means that the neutral π meson couples with the nucleon field through the $\tau_{(3)}(\equiv1)$ or $\tau_{(e)}$ component of the isotopic spin.[5]

TABLE I. Selection rules for the decay of τ and χ mesons.

Decay mode \ Property of meson	S_s	S_v	V_v	V_t	PV_t	PV_{pv}	PS_{pv}	PS_{ps}
$\tau^\pm\rightarrow\begin{Bmatrix}\pi^\pm+\pi^++\pi^-\\ \pi^\pm+\pi^0+\pi^0\end{Bmatrix}$	P	P	T	T	T	·	·	·
$\chi^\pm\rightarrow\pi^\pm+\gamma$	A	A	·	·	·	·	A	A
$\chi^\pm\rightarrow\pi^\pm+\pi^0$ $\tau_{(0)}$	·	T	T	T	P	P	P	P
$\tau_{(3)}$	T	·	·	·	P	P	P	P