Eq. (7) by a factor 1.3 would increase $\bar{E}'$ by ~3 MeV.

(ii) As Z increases, $\bar{E}'$ rises gradually because of a larger contribution from higher-order multipoles which become predominant in heavy nuclei. This can also be seen from the value of $\bar{\nu}R$, ~1.4 in ^{40}Ca and 2.5 in ^{208}Pb, and is confirmed by shell-model calculations.[4] Here exchange effects are not expected to be large because of the small relative contribution of the dipole term to the total transition strength. The smaller slope for very heavy nuclei can be probably explained by a hindrance of higher-order multipoles due to phase-space conditions.

Finally, we want to comment on the present approach. Since Eq. (7) has been obtained in a model-independent way and since the value of $\bar{E}'$ is not sensitively affected by exchange forces, we stress the importance of this parameter which appears to be the most natural one for μ capture.

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Polarized-Proton Inelastic Scattering on ^{32}S and Possible Evidence for a Hexadecapole Phonon State

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Differential cross sections and analyzing powers for inelastic scattering of 24.5-MeV protons from ^{32}S have been measured, with special attention to the excitation of states which occur in the two-phonon region. The coupled-channel theory is used to interpret the excitation of the two-phonon states. An appreciably better fit to the data for the excitation of the second 2^+ state is obtained if a small admixture of the one-phonon state is assumed. However, a strong component of a 4^+ one-phonon state needs to be admixed to the 4^+ two-phonon state.

Various studies of s-d shell nuclei, theoretical as well as experimental, appear to indicate a transition with increasing A from pure rotational spectra to spectra of an anharmonic vibrator. The success of an interpretation in terms of the collective model is rather surprising in this region of light nuclei where one might expect individual-particle aspects to be dominant. The structure of sulfur remains a very puzzling one and we present here a tentative description of the first six states.

In the region of mass $A = 30$–38 where the application of the vibrational model has been previously suggested,[1,2] we have begun a study of ^{32}S and ^{34}S by inelastic scattering of polarized protons at 24.5 MeV. We have obtained good fits to the cross sections and analyzing-power measurements of the first 0^+, 2^+, and 3^- states of ^{32}S and ^{34}S by a coupled-channel analysis using the vibrational model.[3] This model predicts in its simple form a triplet of two-phonon states ($J = 0^+, 2^+, 4^+$) at around twice the energy of the one-phonon state. The states at 3.78 MeV (0^+), 4.29 MeV (2^+), and 4.46 MeV (4^+) have been tentatively identified by previous lifetime measurements[1] and (d, d') scattering[4] as the two-phonon states of ^{32}S.

In general, data for two-phonon states are rather sparse, since the cross sections are low and spacing of the states is small, requiring good energy resolution. However, these states represent a crucial test of the validity of the model.

The details of the experimental setup of the ex-

TABLE I. Optical-model parameters used in the coupled-channel calculations.

Model parameters			V_r (MeV)	r_r (fm)	a_r (fm)	W_i (MeV)	r_i (fm)	a_i (fm)	V_{1s} (MeV)	r_{1s} (fm)	a_{1s} (fm)
VIB	$\beta=0.3$										
$0^+,2^+,0^+,2^+,4^+$			49.42	1.1	0.74	4.55	1.37	0.88	5.29	1.0	0.55
ROT	$\beta_2=0.29$										
$0^+,2^+,4^+$	$\beta_4=0.25$		50.7	1.1	0.73	5.49	1.23	0.85	5.20	1.0	0.54
ROT ASYM	$\beta_2=0.29$	$\gamma=28°$									
$0^+,2^+,2^+,4^+$	$\beta_4=0.21$	$\varphi=0$	50.7	1.1	0.73	5.49	1.23	0.85	5.20	1.0	0.54

periment performed with the polarized-proton beam of the Saclay cyclotron has been already described[3] with the analysis of the 0^+, 2^+, 3^- states of ^{32}S and ^{34}S. We present here the results for the cross sections and analyzing powers of the two-phonon states for angles from 25° to 165°. The overall resolution was around 70 keV. The level at 3.78 MeV was difficult to separate from the level at 4.29 MeV. An upper limit of the cross section for the 3.78-MeV state was obtained for a number of angles.

The optical potential used in the coupled-channel analysis of the two-phonon states was determined previously by a search fit program ECIS-71,[5] where the 0^+, 2^+, 3^- states were coupled (Table I). The cross sections calculated with the vibrational model, coupling the 0^+, 2^+, 0^+, 2^+, 4^+ states, are around 7 times smaller for the multiplet states. We have been led to introduce a mixture of one-phonon and two-phonon states following the method initiated by Tamura for the Ni and Cd isotopes.[6]

A state of spin I will be represented by

$$|I\rangle = \cos\varphi\,|\text{one phonon}\rangle + \sin\varphi\,|\text{two phonons}\rangle.$$

For the first 2^+ state, which is primarily a one-phonon state, φ_1 is small. For the second 2^+ state, which is orthogonal to the first one, the value of $\varphi_2=\varphi_1+\frac{1}{2}\pi$. For $I=4$, the one-phonon component can be a hexadecapole vibration, and for $I=0$, this can be a monopole vibration.

With the program ECIS-72, we calculated cross sections and analyzing powers, coupling the 0^+, 2^+, 2^+, 4^+ states, and we determined for each state the mixture of one-phonon and two-phonon components. These results are presented in Fig. 1 and Table II. The agreement is quite good for the cross section and rather good for the analyzing power measurements. The different characters of one- and two-phonon states have already been studied by (d,d') scattering[4] using the coupled-channel analysis of the angular distributions. Large one-phonon components were indicated for the ${2_2}^+$ and ${4_1}^+$ states. A calculation of (p,p') data with the Jupiter-1 code[7] gives a reasonable agreement for the cross sections of these levels with the same coupling parameters, but is unable to reproduce the analyzing powers because of the absence of spin-orbit deformation.

The 0^+ state, for which the cross section is quite low, was not included in the present work because of the uncertainty in the experimental results. A tentative analysis seems to confirm

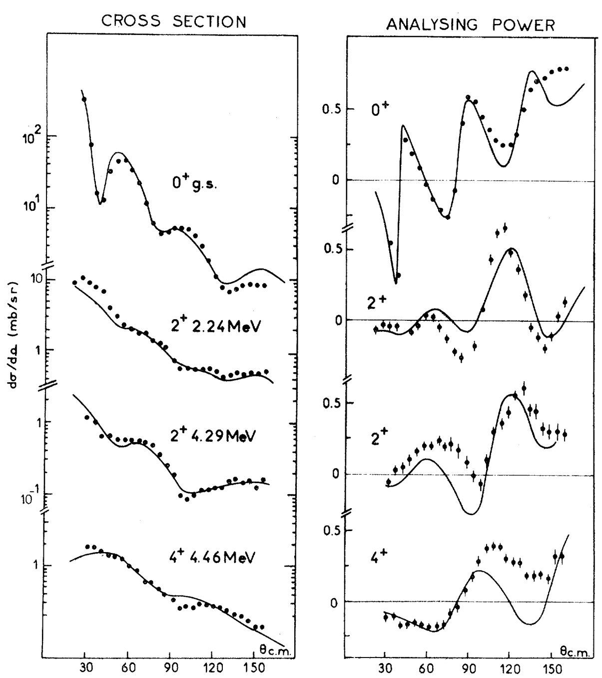

FIG. 1. Angular dependence of the differential cross sections and analyzing powers for inelastic scattering of 24.5-MeV polarized protons from ^{32}S. The solid curve is a coupled-channels calculation coupling the 0^+ (g.s.), 2^+ (2.24 MeV), 2^+ (4.29 MeV), and 4^+ (4.46 MeV) based on the anharmonic vibrational model.

TABLE II. Wave functions of the states with the mixture of one-phonon and two-phonon states.

Energy (MeV)	Level	β	ψ
2.24	2_1^+	0.3	$0.883\lvert\text{one phonon}\rangle - 0.469\lvert\text{two phonons}\rangle$
4.29	2_2^+	0.3	$0.469\lvert\text{one phonon}\rangle + 0.883\lvert\text{two phonons}\rangle$
4.46	4_2^+	0.23	$0.906\lvert\text{one phonon}\rangle - 0.422\lvert\text{two phonons}\rangle$

the two-phonon character for this level, however. The mixture between the two-phonon states can explain deviations from the simple vibrational model such as the nonzero quadrupole moment $Q = -0.175 \pm 0.050$,[8] and the $E2$ transition probability of the two-phonon state to the ground state.[1]

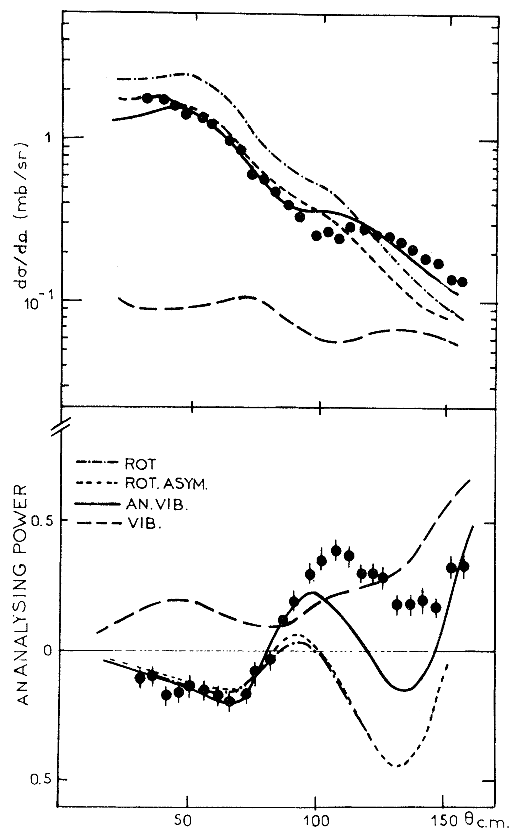

FIG. 2. A comparison of calculations presented in this paper with experimental data. The points are experimental data for the 4^+ level at 4.46 MeV. The curves are coupled-channel calculations. The long-dashed curve is based on the simple vibrational model with coupling of the $0^+, 2^+, 0^+, 2^+, 4^+$ states, the solid curve on the anharmonic vibrational model with coupling of the $0^+, 2^+, 2^+, 4^+$ states, the dot-dashed curve on the rotational model with coupling of the $0^+, 2^+, 4^+$ states, the short-dashed curve on the asymmetric rotational model with coupling of the $0^+, 2^+, 2^+, 4^+$ states.

The 22% mixture of one-phonon component into the 2_2^+ state is in agreement with the value of 20% derived by Häusser[8] and 15% by Ingebretsen[1] from lifetime measurements.

Concerning the interpretation of the 2_2^+ state, several authors[9,10] have suggested that ^{32}S could be looked at as an asymmetric rotator, in analogy with ^{16}O and ^{14}Mg. Accordingly, we used the asymmetric rotational model with $\gamma = 28°$ for calculating the 0^+, 2^+, 2^+, 4^+ states, with the parameters of the optical potential given in Table I. There is reasonable agreement with the data. The best fit was obtained assuming no band mixing between the 2^+ states, but this fit was not as good as with the vibrational picture for the cross section.

Figure 2 shows a comparison between different models for the 4^+ state. The vibrational model gives a very flat cross section which is much too small. The rotational model suggested by (α, α')[11] and (p,p') scattering,[12] and the asymmetric rotational model, give reasonable agreement at forward angles but not at backward angles. Finally, we obtained an excellent fit to the cross section by admixing a one-phonon hexadecapole state. The agreement to the analyzing power is also improved. The description of this state with around 82% one-phonon component and 18% two-phonon component implies that there should be another 4^+ state orthogonal to this one. A possible candidate is the 6.44-MeV state which was observed by by (p,p') scattering[13] at $E_p = 185$ MeV. This state has an $E4$ distribution, and was tentatively assigned a spin and parity 4^+. By electron scattering on ^{32}S,[14] a peak was observed at 6.6 ± 0.2 MeV which could be fitted by $E4$ or $E5$, and would not be in disagreement with a 4^+ assignment to the 6.44-MeV state. The ratio of the cross sections of the 4^+ levels at 4.46 and 6.44 MeV excited by the (p,p') experiment at 185 MeV is in agreement with the mixture of one- and two-phonon states which we have used.

In conclusion, we find that the experimental cross sections and analyzing powers reported here and in Ref. 3 for the 0^+, 2^+, 2^+, 4^+, and 3^- levels can be understood in terms of a coupled-channel vibrational-model calculation where a mixture of one- and two-phonon states is introduced.

In view of these findings, it would be very interesting to have (a) further microscopic calculations on 4^+ states in ^{32}S (e.g., by extending the work of Gunye[15]); (b) decay scheme and lifetime studies of 6.44-MeV state in ^{32}S to clarify its relationship to the 4.46-MeV state.

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Electromagnetic Radiation from an Unmoving Charge*

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Gravitational perturbations in the neighborhood of a point charge can induce electromagnetic radiation even if the symmetry of a configuration indicates that the charge is not moving. Wave equations for the electromagnetic radiation are given in the Newman-Penrose formalism, and the radiation for a simple physical system is calculated and discussed.

In classical nongravitational physics the generation of electromagnetic waves is always associated with the acceleration of charges. When gravitational fields are present, however, the space between an electric charge and an observer is distorted, so the simple classical criterion is insufficient. In gravitational physics the breakdown of this criterion, used with the equivalence principle, leads to some well-known paradoxes, in particular the question of how a freely falling charged particle can radiate.

In this paper we clarify the relationship between the generation of electromagnetic radiation and space-time oscillations.[1] Of particular interest are physical configurations for which it seems reasonable to say that no charge is moving. One such example is that of two uncharged bodies, of equal mass, on opposite sides of a charged particle, and executing circular orbits about the charge (see Fig. 1). We find that this configuration radiates electromagnetic waves and also has a magnetic moment. There is no classical analog of either phenomenon.

In the mathematical approach to such problems we assume that the stress-energy associated with charges and electromagnetic fields makes a neg-