ently the mass parameters still change considerably with λ, although the potential is rather more constant. This effect will be taken account of in a three-dimensional calculation, where the wave function is set up as

$$\psi = \sum_\nu a_\nu(\lambda)\psi_\lambda{}^{(\nu)}(\xi)\exp[(-i/\hbar)\int_0^t E_\lambda{}^{(\nu)}(t)dt] \quad (8)$$

and $\lambda = \lambda(t)$ determined from the classical equation

$$B_{\lambda\lambda}\ddot{\lambda} = -\partial V[\lambda, \xi_0(\lambda)]/\partial\lambda - \gamma\dot{\lambda}. \quad (9)$$

$\xi_0(\lambda)$ can be chosen such as to minimize V for each λ. The introduction of a frictional term with a coefficient γ could yield γ-dependent mass distributions, and a comparison of these with experiment may give information on friction in the fission process.

A second and most important application of the idea of quantized fragmentation dynamics lies in the field of heavy-ion collisions,[10] where it is rather straightforward to calculate fragment distributions after collision, their energy dependence, and their resonance patterns.

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Excitation of a Giant Isoscalar Resonance by α Particles*

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The inelastic scattering of 115-MeV α particles from ^{40}Ca shows an enhancement of the continuum at about 18.25 MeV excitation energy. This observation supports recent electron, proton, and ^{3}He scattering analyses which ascribe similar enhancements at $E_x \approx 63/A^{1/3}$ MeV to an isoscalar giant quadrupole resonance. Although contributions from a monopole excitation cannot be ruled out, attributing all observed yields to a giant quadrupole resonance exhausts only 32% of the energy-weighted sum rule.

Studies of the inelastic scattering of protons,[1-4] electrons,[5-8] and helium ions[9,10] in the region of excitation from 10 to 25 MeV have revealed the existence of a broad resonance. The centroid of the resonance has been found to be consistently 2–3 MeV below the energy at which one expects to find the giant dipole resonance (GDR) as determined by photonuclear experiments. Furthermore, the strength of the resonance is much larger than that predicted by the energy-weighted sum rule for isovector dipole transitions. Although the electron data and some of the proton data[11] are consistent with a monopole assignment, the interpretation of the resonance as an isoscalar quadrupole vibration is generally favored. A monopole excitation is expected to appear at a higher energy because of the incompressibility of nuclear matter. An isovector quadrupole vibration is also expected to be associated with larger field energies. More recent inelastic proton data,[12] as well as the inelastic helium-ion data, tend to favor the quadrupole assignment. A precise determination of the transition strength of the giant quadrupole resonance (GQR) is difficult since the GQR is not clearly separated from the GDR. Furthermore, the continuum background is not well understood. Nonetheless, the reported measurements suggest that the GQR has an appreciable fraction of the energy-weighted sum-rule strength.

The existence of a GQR as well as the strength with which it is excited is of considerable theoretical importance. This experiment was undertaken to determine whether or not the proposed GQR is excited in α scattering. Inelastic α-particle scattering will only strongly excite the isoscalar modes of vibration. Thus overlap from the neighboring GDR is avoided. Furthermore, α particles are known to excite 0^+ levels weakly, except by inelastic scattering to backward angles.[13] The α particle should therefore be a sensitive probe for studying the GQR.

α particles were accelerated to energies of 79.1 and 115.4 MeV by the 88-in. Texas A & M University variable-energy cyclotron. The energy of the α particles was determined by passing the beam through a 159° analyzing magnet.[14] Self-supported metal foils of ^{40}Ca and ^{208}Pb were used as targets. Natural calcium, which is 97% ^{40}Ca, was used to prepare the calcium target. $Pb(NO_3)_2$ isotopically enriched to 99% ^{208}Pb was used to prepare the lead target. The targets were in the neighborhood of 1–2 mg/cm^2 thick. The scattered α particles were analyzed by an Enge split-pole spectrograph,[15] and were detected in a 1×30-cm^2 position-sensitive detector placed on the focal plane of the spectrograph. The detector was a single-wire, charge-division proportional counter. A plastic scintillator placed behind the counter gave a measure of the total energy of the detected particle. The scintillator signal was used to gate signals from the proportional counter, thereby eliminating the unwanted x-ray and γ-ray background. The low-energy continuum of deuterons from the (α, d) reaction was removed from the α-particle spectrum by placing a digital baseline on the summed signals from the ends of the counter. The dispersion of the spectrograph allowed the detector to cover ~12 and ~21 MeV of excitation at bombarding energies of 79.1 and 115.4 MeV, respectively. The region of excitation energy from 0 to 25 MeV was studied at laboratory scattering angles between 3 and 25° for each target nucleus and bombarding energy.

In the case of ^{208}Pb, indications of the resonance were observed at 115.4 MeV bombarding energy, but these results have not been analyzed. Recent measurements[16] at this laboratory using surface-barrier detectors corroborate the existence of a resonance in the ^{208}Pb(α, α') spectra near $63/A^{1/3}$ MeV excitation energy at 115 MeV bombarding energy. An unambiguous indication of the GQR was found only for ^{40}Ca at a bombarding energy of 115.4 MeV. As is shown in Fig. 1, a peak ~3 MeV wide was observed at 18.25 ± 0.25 MeV of excitation in the spectrum of α particles inelastically scattered from ^{40}Ca. The peak was observed at each angle at which the experiment was performed. Between 8 and 12° the peak is obscured by the ^{1}H(α, α) elastic peak. The background was approximated by linearly extrapolating the higher excitation region into the resonance region. This procedure was chosen because of its simplicity and because the background continuum is not understood in detail. In Fig. 1 the approximation used for the background continuum is indicated by a dashed line under the resonance. It seems clear that this procedure will overestimate the background.

The angular distribution for the excitation of the resonance is shown in Fig. 2. We have assigned a 10% uncertainty due to the background subtraction procedure. The remaining uncertainty is that due to the normalization procedure. The solid curve in Fig. 2 is a prediction of the angular distribution for a quadrupole surface vibration, while the dashed curve is that of a monopole breathing mode. The calculations were done in the distorted-wave Born approximation using the computer code DWUCK.[17] Form factors derived from a generalized optical potential were

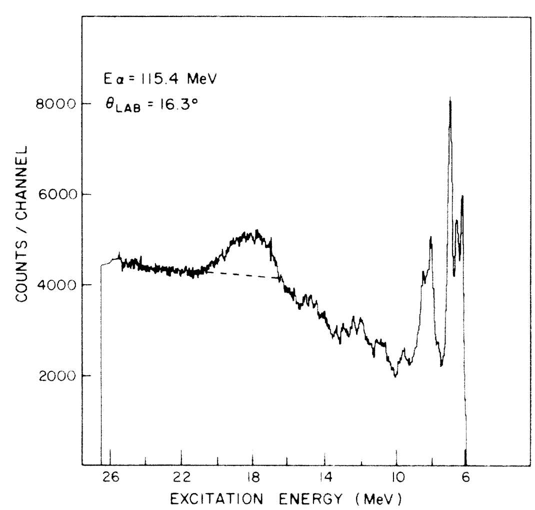

FIG. 1. A spectrum of inelastically scattered α particles between 6 and 27 MeV of excitation in ^{40}Ca. Dashed curve, approximation used for the continuum background.

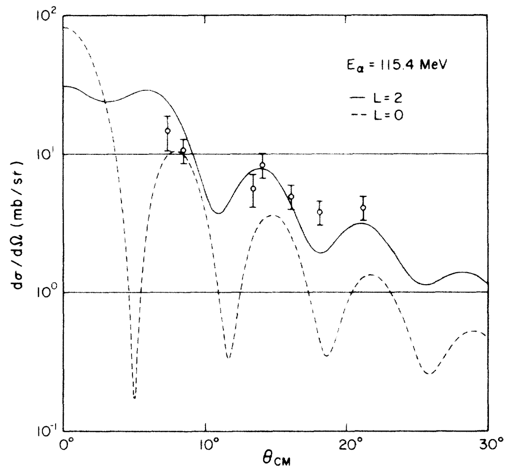

FIG. 2. Experimental differential cross sections for the excitation of the resonance observed in ^{40}Ca compared with distorted-wave Born-approximation predictions.

used for both the monopole[11] and quadrupole[18] cases. The four-parameter optical potential derived by fitting the previously published elastic scattering data at 115.4 MeV [19] has $V = 109.7$ MeV, $W = 61.5$ MeV, $r_0 = 1.35$ fm, and $a = 0.7$ fm. The deformation length $\beta_0 R$ for the monopole case was calculated assuming a one-phonon breathing mode for a uniform mass distribution which exhausts the almost model-independent energy-weighted sum rule.[11] In the case of the quadrupole vibration, the deformation parameter for the best fit is $\beta_2 = 0.14$.

The dashed curve in Fig. 2 represents all of the transition strength available to a monopole breathing mode. Because of the approximation used for the background continuum, the data represent at worst a lower limit. Furthermore, since α particles weakly excite 0^+ levels, the quadrupole assignment to the resonance is favored. Although contributions from a monopole excitation cannot be ruled out, attributing all observed yields to a GQR exhausts only 32% of the energy-weighted sum rule. Another 13–25% can be accounted for by lower-lying 2^+ levels.[20,21] Hence a significant fragment of isoscalar quadrupole strength remains unaccounted for.

Thus the inelastic scattering of 115-MeV α particles provides one more weak piece of evidence in support of the GQR. The principal defect in the present case is the inability to rule out an $E0$ transition based on the sum-rule limits. This stems in part from the large background in the region of interest. The angular distribution of the background as subtracted has the same shape as the continuum in the $E^* \approx 19$–23-MeV region. Since the background, as subtracted herein, is almost an order of magnitude larger than the resonance yield, present estimates of the latter may be subject to larger errors than quoted. In order to obtain more reliable information as to the nature of both the background continuum and the resonance, investigations of the excitation and decay modes in the GQR region in many nuclei have begun using several projectiles. Experiments on the $(\alpha, \alpha'\gamma)$ and $(\alpha, \alpha'p)$ reactions should provide information on the nature of α particle scattering to the continuum region.

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Induced Decay of the Neutral Vacuum in Overcritical Fields Occurring in Heavy-Ion Collisions*

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In critical or nearly critical heavy-ion collisions, induced as well as spontaneous energyless e^-e^+ pair creation result in the decay of the neutral vacuum. Induced transitions from the negative-energy continuum into a vacant molecular 1s level can occur even in the absence of diving and produce a substantial enhancement and broadening of the previously considered spontaneous positron spectrum. Total cross sections of 5 b have been calculated for U-U collisions.

Intermediate quasimolecules, which will be formed in the collision of very heavy nuclei, show with respect to their electronic structure all properties of superheavy atoms.[1-5] In the case that the charge number Z_1+Z_2 of the colliding nuclei is larger than the critical charge number $Z_{cr}\simeq 169-172$, the $1s_{1/2}$ level enters the negative-energy continuum. If the K shell is ionized, e^+e^- creation results. This has to be interpreted as the decay of the neutral vacuum, which is unstable in overcritical fields.[4]

Up to now calculations were done for the spontaneous positron creation.[6] The cross sections will be increased, however, by two effects because of the nonadiabacticity of the heavy-ion collision: First, during the "diving" process e^+e^- pairs are created, in addition to the spontaneous ones, by induced autoionization. Second, before and after the diving a large number of positrons will be created by induced transitions from the negative-energy continuum to the $1s_{1/2}$ level. The latter transitions will occur even if there is no level-diving during the collision.

To calculate the total transition amplitude, all the transitions, from the negative-energy continuum to the $1s_{1/2}$ level, along the classical ion path must be added coherently.[7] These transitions may be approximately grouped into first, pre- and after-diving amplitudes $C_{PA,E}$, and second, the during-diving amplitude C_D. Then we have

$$C_{PA,E}=\int_{-\infty}^{-t_{cr}}dt'\exp\{(i/\hbar)\int_{-\infty}^{t'}dt''[E-E_{1s_{1/2}}(t'')]-(2\hbar)^{-1}\int_{-\infty}^{t'}\Gamma(t'')dt''M_E(t')\}$$
$$+\int_{t_{cr}}^{\infty}dt'\exp\{(i/\hbar)\int_{-\infty}^{t'}dt''[E-E_{1s_{1/2}}(t'')]-(2\hbar)^{-1}\int_{-\infty}^{t'}\Gamma(t'')dt''M_E(t')\},\tag{1}$$

where

$$M_E(t')=-\langle\psi_E(t')|(\partial/\partial t')|\varphi(t')\rangle\tag{2}$$

and $\Gamma(t'')$ represents the decay $1s_{1/2}$ level due to the interaction with the continuum (to be determined later) and t_{cr} denotes the "critical" time at which diving occurs. $|\psi_E\rangle$ and $|\varphi\rangle$ are the wave functions for the positron (negative-energy continuum) and the $1s_{1/2}$ vacancy, respectively. The time integration can be replaced by an integration over dR/v_R along the ion hyperbola, where R is the distance of the two ions and v_R the radial velocity.

The matrix element $M_E(t')$ can be computed by expanding the bound state $|\varphi(t')\rangle=|\varphi(R)\rangle$ and the continuum states $|\psi_E(t')\rangle=|\psi_E(R)\rangle$, which are eigenstates of the Hamiltonian $H(R)$, about the $1s_{1/2}$ diving radius R_{cr}; i.e.,

$$|\varphi(R)\rangle=f(R)\{|\varphi_{cr}\rangle+\int dE'g_{E'}(R)|\psi_{E',cr}\rangle\},\quad |\psi_E(R)\rangle=a(E,R)\{|\varphi_{cr}\rangle+\int dE'b_{E'}(E,R)|\psi_{E',cr}\rangle\},\tag{3}$$

with the following normalizations:

$$\langle\varphi(R)|\varphi(R)\rangle=1,\quad\langle\psi_E(R)|\psi_{E'}(R)\rangle=\delta(E-E'),\quad\langle\psi_E(R)|\varphi(R)\rangle=0.\tag{4}$$

In the expression (3), the higher bound states, i.e., $2p_{1/2}$, $2s_{1/2}$, etc., have been neglected. Such effects are expected to be most important at large ion separations where the matrix element $M_E(t)$ is