number of sites sampled by an exciton in its lifetime (20 nsec) is $\sim 10^6$. This gives us a value of $t = 10^{-14}$. Equation (1) then becomes

$$R_a = 1.24 \times 10^{-8} n^2, \quad (2)$$

where a value of 3.38×10^{21} has been subsituted for N. The bimolecular rate constant due to unimolecular autoionizing decay is in striking agreement with the γ_S postulated by Bergman, Levine, and Jortner to explain the results of their experiments.

If we assume the autoionizing mechanism to be the correct one, Eq. (2) tells us that autoionization of excitons will always be more important than the mutual annihilation of two excitons localized on two different sites, since the rate constant for the former process is three orders of magnitude larger than the rate constant for the latter process. Consequently, what has usually been assumed to be an exciton-exciton annihilation mechanism is really the autoionization of anthracene molecules, a process thus far not believed to occur.

This Letter actually poses more questions than answers. What is the nature of the excited state from which autoionization takes place? Can autoionization be observed by direct excitation of the anthracene crystal to the second excited singlet state, which overlaps the conduction-band edge believed to be at about 4.1 eV,[8] by suitable means? It is hoped that this Letter will motivate further experimental and theoretical studies to answer these and other questions.

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COULOMB DISPLACEMENT ENERGIES OF Ca-Sc ISOBARIC PAIRS*

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A new experimental technique was used to measure Coulomb displacement energies ΔE_C in the Ca-Sc isobaric pairs with $A = 44$, 46, 48, and 50. The reaction $Ca^{46}(He^3, d)Sc^{47}$ was used to measure this quantity for $A = 47$. This permits analysis of ΔE_C for all the isobaric pairs from $A = 41$ to 50, for the ground states and for several excited states, which yields a consistent picture.

The systematic accurate measurement of Coulomb energy differences ΔE_C between ground states (g.s.) and their isospin analogs has been the subject of a number of recent investigations.[1-3] A reaction for studying the analogs of 0^+ ground states is suggested by the property of the (t,p) reaction to strongly populate 0^+ states.[4] The (He^3,p) reaction, with a singlet deuteron transferred, is the isospin analog of the (t,p) reaction; we may therefore expect it to select the ground-state analogs, reduced in yield by the isospin vector-coupling coefficient which gives a factor of $(2T+2)^{-1}$. In fact, the $Ca^{40}(He^3,p)Sc^{42}$ (g.s.) transition[5] has been found to show the same characteristic $l = 0$ angular distribution as the (t,p) reaction.[4] We have studied the (He^3,p) reaction on the five even-A stable isotopes of Ca by use of the 12-MeV He^3 beam of the Argonne tandem Van de Graaff, with two angular settings of the broad-range magnetic spectrograph. Evaporated targets of ~ 50 $\mu g/cm^2$ of each isotope were used. In each case one strong proton group was found in the expected region of excitation; its energy shifted with the angle of observation in a way consistent with the target mass. To confirm our identification of the analog state in the case of Sc^{48}, we used the weak 15-MeV He^3 beam (obtainable with He^- injection) to expose a plate for the reaction $Ca^{48}(He^3, t)Sc^{48}$.[6] The value of ΔE_C was known for all the odd-A calcium isotopes except Ca^{47}, and that for the latter was obtained

here from the reaction $Ca^{46}(He^3, d)Sc^{47}$. The values of ΔE_C from the present work as well as from other experiments are given in Table I and Fig. 1. It is evident from Fig. 1 that, while ΔE_C is quite constant within the $1f_{7/2}$ configuration, states involving $2p_{3/2}$ components in their wave functions behave differently.

Previous macroscopic calculations[1] of Coulomb energies have assumed constant nucleon densities with $R \propto A^{1/3}$, yielding $\Delta E_C \propto Z/A^{1/3}$. A naive microscopic model, using a harmonic oscillator well, predicts that ΔE_C will remain constant within a shell so long as Z is constant—the charge distribution being, by

Table I. Coulomb energies of Ca-Sc isobaric pairs.

Isobaric pair	State	ΔE_C[a] (MeV)	Reference
Ca^{41}-Sc^{41}	ground	7.283	b, c
	$\frac{3}{2}^-$	6.985	b, c, d
Ca^{42}-Sc^{42}	ground	7.214[e]	f, g, h
	$(5.86, 0^+)$	7.174	g, h
Ca^{43}-Sc^{43}	ground	7.246	i, j, f
	$(\frac{3}{2}^-)$	7.123	i, j
Ca^{44}-Sc^{44}	ground	7.228	f, h
Ca^{45}-Sc^{45}	ground	7.236	f, j
Ca^{46}-Sc^{46}	ground	7.209	f, h
Ca^{47}-Sc^{47}	ground	7.194	k, h
	$(\frac{3}{2}^-)$	7.086	k, l
Ca^{48}-Sc^{48}	ground	7.175	f, g, h
Ca^{49}-Sc^{49}	ground	0.089	m, n
Ca^{50}-Sc^{50}	ground	7.010	g, h

[a]All ±~0.015 MeV except as otherwise noted.
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[g]Ref. 4.
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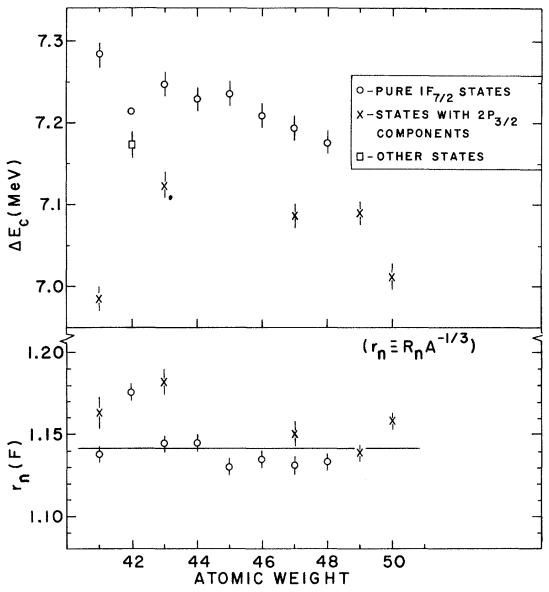

FIG. 1. Coulomb-energy differences ΔE_C (upper graph) and neutron-well radius constants r_n (lower) for various Ca-Sc isobaric pairs. Some values of ΔE_C are for excited states. The values of r_n were derived from the ΔE_C by the method described in the text. The error bars represent the uncertainties in ΔE_C and do not reflect uncertainties in the charge distribution or the other parameters nor in the assumptions entering into the calculation.

definition, the same for all isotopes.[2] This, however, is not a good description, because the charge distributions for the $Ca^{40,44,48}$ isotopes are found to be different from each other.[7] We have calculated ΔE_C by using $1f_{7/2}$ and $2p_{3/2}$ wave functions in a Woods-Saxon well.[8] The behavior of ΔE_C as a function of neutron binding energy[9] is shown in Fig. 2, where it is seen that the two curves have quite different slopes and continue smoothly into the unbound region.[10] The difference between the calculated $1f_{7/2}$ and $2p_{3/2}$ Coulomb energies for the proper binding energies in Ca^{41} is in good agreement with experiment, and this seems to us to confirm the gross validity of our approach.[9]

Using experimental charge distributions,[7] the present calculations consisted of a simultaneous variation of the depth and the radius (V_0 and R_n) of the neutron well to fit the known binding energy of the excess neutrons and the observed Coulomb energy. Interpolated values of the charge distribution were used where no experimental measurements were available.

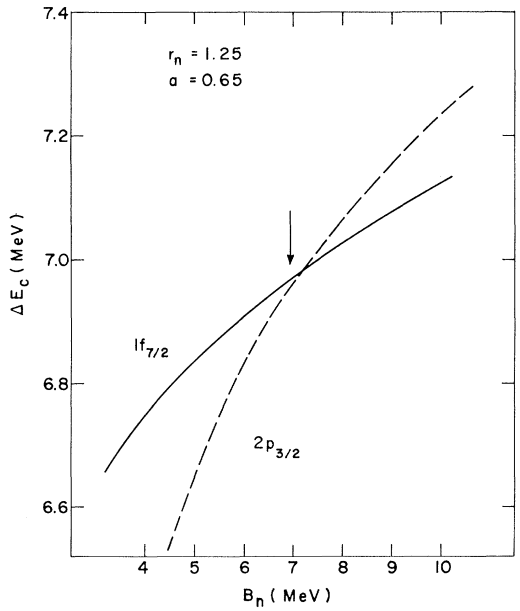

FIG. 2. Coulomb-energy difference for single-particle $1f_{7/2}$ and $2p_{3/2}$ states, calculated in a Woods-Saxon well as described in the text, as a function of the binding energy of the neutron state (or well depth). The arrow indicates zero binding for the proton state.

The neutron well diffuseness was fixed at 0.65 F and a spin-orbit strength of 10 MeV was used throughout. The results in Fig. 1 indicate that R_n follows the $A^{1/3}$ dependence very closely. For the $\frac{3}{2}^-$ states in Ca^{41}-Sc^{41} we took the center of gravity of the two strongest transitions, which exhaust most of the single-particle strength; for Ca^{43}-Sc^{43} and Ca^{47}-Sc^{47}, only the strongest $\frac{3}{2}^-$ state was included. Consequently, the deviation in r_n for the $A = 43$, $\frac{3}{2}^-$ point may be caused by the fact this state is not purely the single-particle state. The deviation for $A = 42$ may possibly be caused by an isospin admixture, Sc^{42} being the only nucleus here with $T_z = 0$ so that the energy separation between $T = 0$ and $T = 1$ states of simple configuration is less than in any of the other nuclei.[11] An alternative explanation would be an anomalously large deformation in Ca^{42}.

Even though the neutron well radius grows as $A^{1/3}$, calculations[12] predict that the radius of the actual neutron mass distribution in such a well increases faster than $A^{1/3}$. This result was attributed to the nuclear symmetry term, which also explains the observed behavior of the radius of the proton mass distribution (charge distribution) which grows less rapidly than $A^{1/3}$. The net nucleon mass radius for Ca isotopes in the calculation of Perey and Schiffer remained very nearly proportional to $A^{1/3}$, which seems consistent with the present result for the potential-well radius and is in contrast to the work of Wilkinson, Hay, and Mafethe,[13] who used a constant well radius throughout the $1p$ shell in their calculations of charge distributions and Coulomb energies.

The measurement of ΔE_C may well be a useful tool in nuclear spectroscopy; we have an example of this in the 5.86-MeV state in Ca^{42} which was seen strongly in the reaction[4] $Ca^{40}(t, p)Ca^{42}$ with an angular distribution characteristic of $l = 0$. A 0^+ state of this type, arising from the $(2p_{3/2}{}^2)_0$ configuration, may be expected in this region of excitation energy. However, because of its much smaller binding energy, such a state would have a Coulomb energy difference about 250 keV less than that for the ground state. In fact we observe the analog state very clearly in the spectrum and the Coulomb energy is only 40 keV less than that of the ground state. This suggests strongly that this state arises from the $(f_{7/2}{}^2)_0$ configuration coupled to a 0^+ core-excited state of Ca^{40}, and is populated in the (t,p) reaction by way of such admixtures in the ground state of Ca^{40}. Coupling to the 0^+ state of Ca^{40} at 3.35 MeV would give the observed ΔE_C if we assume it to have the same charge distribution as the ground state; a higher 0^+ state with a more diffuse or deformed charge distribution could also fit our result. It should be noted that a core-excited state will contain some $1f_{7/2}$ components and the Coulomb energy is therefore not quite correctly treated here. However, no other plausible configuration—such as $(f_{5/2}{}^2)_0$—can explain this high value of the Coulomb energy. It seems clear that in assigning configurations to nuclear states, results such as this provide useful information.

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[10]The method of calculation for the continuum case automatically takes into account the Thomas-Ehrman shift, which is a property of calculations involving a boundary. It is clear from Fig. 2 that, contrary to the statement of Ref. 2, the Thomas-Ehrman shift does not account for the anomaly in the $2p_{3/2}$ Coulomb energies; it is not simply a matter of a state being bound or unbound.

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AVERAGE WIDTHS FOR HIGH-ENERGY RADIATIVE TRANSITIONS*

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Although the partial radiation widths of the high-energy states excited by neutron capture have been studied for many years, little is known about the average widths of transitions from many initial states to individual final states. The reason for this dearth of information is that the broad Porter-Thomas distribution[1] that governs the widths of transitions from individual initial states prevents the thermal-neutron-capture γ rays from giving useful averages, and it is not technically feasible to measure the spectra of enough individual neutron resonances to deduce average widths with the required accuracy. We have bypassed these difficulties by directly measuring the average γ-ray spectrum formed when neutrons that are distributed in a relatively broad band of energy are captured in many resonances. In this paper we describe the application of this new method to a study of the dependence of the radiation width on γ-ray energy.

Basically, the method of measurement consists of observing, with a Ge-diode γ-ray spectrometer, the capture γ rays emitted by a B^{10}-surrounded target that is placed in a high-flux region of a nuclear reactor. The boron absorber selectively removes low-energy neutrons and the $1/E$ spectrum of the incident neutron flux assures a low intensity of energetic neutrons. The combination limits the energies of the neutrons absorbed in the sample to a band that is broad enough to contain many resonances but narrow enough to preserve the excellent resolution of the Ge diode. A key concept of the measurement is that, even though there is a great variability in the magnitude of the contributions by the various resonances, a meaningful average is obtained if one has contributions from enough resonances.

The experiment outlined above is feasible only because of the high sensitivity of the internal-target facility[2] in the reactor CP-5. Here, the target is mounted in the high-flux region of a tube that passes straight through the reactor tangent to the core. Both thermal neutrons and a $1/E$ spectrum of epithermal neutrons impinge on the target from all directions. Capture γ rays from the target are viewed by a Ge-diode detector located outside the reactor, about 5 m from the target. A carefully designed collimation system ensures that the main source of radiation viewed by the detector is the target of interest.

In our measurements, the thermal flux at the target was 3×10^{13} sec^{-1} and the epithermal flux was roughly $(18/E)\times10^{11}$ eV^{-1} cm^{-2} sec^{-1}. The solid angle viewed by the detector was about 2×10^{-8} of the unit sphere. The detector had an active volume of 4 cm^3 and gave a resolution width of about 8 keV at 7 MeV.