[14]Similar ideas are contained in the work of W. E. Lamb and M. O. Scully, in *Polarization, Matter and Radiation* (Presses Universitaire de France, Paris, 1969) and P. A. Franken, in *Atomic Physics*, edited by V. Hughes *et al.* (Plenum, New York, 1969), p. 377. These investigations contain numerical calculations in agreement with the observed photoelectric effect.

PHYSICAL REVIEW D VOLUME 4, NUMBER 6 15 SEPTEMBER 1971

Collapsed Nuclei*

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(Received 29 March 1971)

We discuss the observational consistency, possible properties, and detection of collapsed nuclei C_A. These may be considered as elementary particles with mass number $A > 1$ and of much smaller radius than ordinary nuclei N_A. The existence of C_A of (perhaps much) lower energy than N_A is observationally consistent if N_A are very long-lived isomers against collapse because of a "saturation" barrier between C_A and N_A. Barrier-penetrability estimates show that sufficiently long lifetimes $\gtrsim 10^{31}$ sec are plausible for $A \gtrsim 16$–40. The properties of C_A are discussed using composite baryon and quark models; small charges and hypercharges and, especially, neutral C_A are possible. C_A can be effectively a source or sink of baryons. Some astrophysical implications are briefly discussed, in particular the possible large scale presence of C_A and the possibility that accelerated collapse in massive objects may be a source of energy comparable to the rest mass.

I. INTRODUCTION

We consider the possibility of collapsed nuclei and conjecture about their possible properties and about the observational consequences of their existence. By collapsed nuclei C_A we understand systems with baryon number $A > 1$ and with (presumably much) smaller radii than normal nuclei N_A. Collapsed nuclei are thus best regarded as elementary particles, in contrast to ordinary nuclei. C_A of (perhaps much) lower energy than N_A can be consistent with observation if N_A are extremely long-lived isomers. We show that this is possible for moderate A. States with $A = 2$ and nonzero strangeness have been previously considered[1] using SU_3. However, these states consist of baryons not bound or only loosely bound together.

Our conjectures arose on the one hand from quark models which give no obvious reason why tightly bound systems of quarks with $A > 1$ should not exist. Secondly, recent phenomenological nuclear forces with soft (or momentum-dependent) repulsive cores[2] do not necessarily satisfy the saturation conditions.[3]

The observational consequences of the existence of C_A are dependent on the properties conjectured for C_A. To obtain some indications about these we have considered two types of models for C_A, namely quark models with quarks as the constituents, and composite hadron models with the known hadrons as the constituents. Some possible astrophysical implications are also briefly discussed.

II. SATURATION CONDITIONS; "STABLE NUCLEI AS ISOMERS"

Since the A-baryon Hamiltonian H_A is not known for collapsed conditions which could be vastly different from normal ones, we use $H_A(C)$ and $H_A(N)$ for the appropriate forms of H_A. Collapsed and normal conditions, in particular states, are denoted by superscripts (C) and (N), respectively. Some speculations about $H_A(C)$ are given in Sec. IV in connection with the discussion of the properties of C_A. For the time being we merely assume that the radius R_C of C_A is much less than the radius $R_N = r_0 A^{1/3}$ of N_A and we consider two options for R_C: (1) R_C is roughly constant, about the nuclear-force range ($\lesssim 0.5$ F) with C_A resembling the usual collapsed state with all nucleons (generally hadrons) within R_C; (2) $R_C \approx r_C A^{1/3}$ with $r_C \lesssim 0.4$ F, corresponding to saturation at very high densities, perhaps appropriate to a saturating quark model. The binding energy calculated with a trial function is barred. The exact eigenvalue is unbarred; e.g., for $H_A(N)$ the binding energies $\bar{B}_A^{(C)}(N)$ and $\bar{B}_A^{(N)}(N)$ are for collapsed and normal trial functions, respectively, and $B_A(N)$ is the exact energy.

One argues that $H_A(N)$ is unacceptable if $\overline{B}_A^{(C)}(N) > B_A^{\text{expt}}$ for some A, since $B_A(N) > \overline{B}_A^{(C)}(N)$, and hence $B_A(N) > B_A^{\text{expt}}$ in apparent conflict with observation. However, this conclusion is not inescapable (even if A includes stable nuclei), since $H_A(N)$ most probably has a (lowest) collapsed eigenstate (a collapsed trial function was used), and if $H_A(N) \neq H_A(C)$ nothing can be concluded about C_A; in particular, about its existence. [Only for a *normal* trial function and $\overline{B}_A^{(N)}(N) > B_A^{\text{expt}}$ could one reasonably conclude that $H_A(N)$ is unacceptable.] Generally, whether or not the saturation conditions are satisfied implies nothing about C_A, since $H_A(C)$ is likely to be very different from $H_A(N)$.

We now study the implications of *postulating that H_A is such that the collapsed state C_A is the lowest state for values of A which include some stable nuclei*. Although C_A is not observed (to date), the well-known phenomenon of isomerism shows that this need not imply its nonexistence. We thus modify the "saturation" requirements on N_A and the statements about C_A as follows. C_A may be energetically lower than N_A, and H_A is acceptable, if

$$B_A(C) > B_A(N) \text{ for } A \geq A_{\min}, \tag{1a}$$

and

$$\tau_A(N) > \tau_{\text{obs}} \approx 10^{31} \text{ sec} \approx 10^{24} \text{ yr for } A \geq A_{\min}. \tag{1b}$$

Here $\tau_A^{(N)}$ is the lifetime of N_A for decay into C_A, while τ_{obs} is the experimentally observable limit for a decay time. The value 10^{31} sec corresponds to about one disintegration per mole per year and is very conservative even for readily detectable disintegrations involving large energy releases.

Conditions (1a) and (1b) imply that H_A gives a "saturation" barrier which hinders transitions between C_A and N_A. Such a barrier, associated with collective volume changes, is a consequence of the observed nuclear saturation and is therefore obtained even for models with $H_A(C) = H_A(N)$ which are consistent with conventional nuclear forces (possibly with modifications which are negligible for N_A). Examples are conventional two-body potentials with a soft core, or with suitable momentum dependence (repulsive at fairly low momenta of the order of the Fermi momentum and strongly attractive at very high momenta), or saturating two-body forces plus many-body forces, which have a small effect at normal densities but are strongly attractive at very high ones.[4] (As discussed in Sec. IV relativistic effects favor C_A relative to N_A.) *There is thus no obvious conflict with observation if C_A is lower in energy than N_A and if also N_A are extremely long-lived isomers.*

If N_A is lower in energy than C_A, i.e., if $B_A(C) < B_A(N)$, then with a saturation barrier between N_A and C_A it is now C_A which is metastable. A lifetime condition is now, however, unnecessary for observational consistency. If, however, $\tau_A^{(C)} \gtrsim \tau_{\text{obs}}$, then C_A is now effectively stable. This possibility is complementary to that where C_A is the lower state. It is even a natural one for $A < A_{\min}$, if $B_A(C)$ and the saturation barrier vary smoothly with A such that $B_A(C) > B_A(N)$ for $A \geq A_{\min}$. Such a crossover at $A_{\min}$ of $B_A(C)$ and $B_A(N)$ as functions of A could be expected for constant R_C (where the number of bonds increases rapidly with A) and perhaps even for $R_C \propto A^{1/3}$ if surface effects decrease fast enough with A.

That ordinary nuclei are isomers need not be considered a particularly outrageous suggestion in view of well-known examples of isomers. Mundane examples[5] are diatomic molecules and the associated "collapsed" atom (e.g., the D-D molecule and He atom). For small A the molecule is metastable (fusion favored) and vice versa for large A (spontaneous fission favored). Related to atom-molecule isomerism is the Jahn-Teller selection rule. Examples where the barrier is a collective effect, but associated with changes in shape, are the fission isomers[6] whose lifetimes can be of the order of 10^{-3} sec. These also are states in an external well shallower than the interior well.

III. LIFETIME OF ORDINARY NUCLEI AGAINST COLLAPSE

To estimate $\tau_A^{(N)}$ we use

$$[\tau_A^{(N)}]^{-1} = \nu P\,, \tag{2}$$

where $P = 10^{-p}$ is the penetrability of the saturation barrier W and ν is the frequency of attempts by N_A on W. We assume $W(r)$ depends on the collective radial coordinate r, corresponding to spherical distortion (compression or dilation) of the whole nucleus. Collapsed conditions correspond to a central hole (radius R_C) and normal ones to a shallow outer valley of radius R_N. The assumption $W = W(r)$, i.e., that only the dependence on r need be considered, implies that the collapse is "direct" and proceeds by the "shortest" path, and not by a longer one perhaps involving deformations or other degrees of freedom. This is a natural assumption, aside from the difficulty of making any other.

The frequency ν is that of the "breathing" mode and is determined by the radius $R_N = r_0 A^{1/3}$ of N_A and by the nuclear-compressibility coefficient K.[7] Thus $\nu^{-1} \approx 7 \times 10^{-23}\,(100/K)^{1/2} A^{1/3}$ for $r_0 = 1.1$ F and K in MeV. For $A \approx 40$ and $K = 200$ MeV (a popular value) one obtains $\nu^{-1} \approx 1.7 \times 10^{-22}$ sec. Thus $\tau_A^{(N)} \gtrsim 10^{31}$ sec requires $P \lesssim 10^{-53}$ or equivalently $p \gtrsim 53$.

For P we use

$$P = e^{-2C} \text{ with } C = (2M/\hbar^2)^{1/2} \int_{R_C}^{R_N} [W(r)]^{1/2}\, dr, \tag{3}$$

where $M \approx AM_N$ is the mass of N_A. The zero-point energy of N_A is negligible and reflection effects, etc. from $r \leq R_C$ are neglected. Knowledge of $W(r)$ implies knowledge of the equation of state of nuclear matter to extremely high densities. Even for normal densities this equation, in particular the compressibility coefficient K, is not well known. We thus parametrize $W(r)$ in terms of R_N, R_C, K, and a shape parameter x. Thus near R_N we have

$$W(r) - W(R_N) = AK(r - R_N)^2 / 2R_N^2. \tag{4}$$

Several extrapolations to R_C were considered which all satisfy Eq. (4) for $r \geq \bar{R} = \frac{1}{2}(R_N + R_C)$ and are characterized by x. One finds

$$C = x r_0 (KM_N/\hbar^2)^{1/2} A^{4/3} (R_N - R_C)^2 / 2R_N^2, \tag{5}$$

where $0.25 \leq x \leq 1$ for the shapes considered. Thus if $W(r)$ is given by Eq. (4) for $R_C \leq r \leq R_N$, then $x = 1$, whereas if $W(r) = 0$ for $r < \bar{R}$ (zero cutoff), one has $x = 0.25$. For intermediate shapes, x has intermediate values [$x = 0.75$ for a horizontal cutoff for $r < \bar{R}$, and $x = 0.5$ for $W(r)$ symmetric about $\bar{R}$]. Equation (5) gives $W(R) \approx 2$ GeV for $K = 200$ MeV and $A \approx 100$. The shapes which give $x < 1$ are all conservative [i.e., W is less than the value given by Eq. (5)], and $x > 1$ is also quite possible. In any case one expects $x = O(1)$. There are also uncertainties due to inadequate knowledge of K. Thus the value $K \approx 200$ MeV is rather uncertain and larger values, e.g., $K \gtrsim 300$ MeV, are quite possible. For $K \approx 300$ MeV, p would be larger by a factor of about 1.22.

With $p_0 = p(R_C = 0)$ and for $K = 200$ MeV and $r_0 = 1.1$ F one obtains $p_0/x \approx 6$, 16, 40, 137, 467, and 1170 for $A = 4$, 8, 16, 40, 100, and 200, respectively; for $R_C = 0.5$ F the corresponding values are $p/x \approx 3$, 9, 27, 104, 376, and 995. For $R_C = r_C A^{1/3}$ one has $p/p_0 = (r_0 - r_C)^2 / r_0^2 = 0.64$ and 0.36 for $r_C = 0.2$ and 0.4 F, respectively.

These estimates, inspite of their uncertainties, clearly demonstrate that $\tau_N^{(A)} \gtrsim \tau_{\text{obs}}$ can be satisfied for $A \gtrsim 16$–40 and perhaps for even smaller values of A. If the existence of C_A is accepted, then consistent with Eq. (1b) one only further requires that $A_{\min}$ be larger than the minimum value of A required for $\tau_N^{(A)} \gtrsim \tau_{\text{obs}}$. Our lifetime estimates are probably not too relevant if A is considerably larger than $A_{\min}$, since then only a part of N_A (corresponding to an effective value of A closer to $A_{\min}$) may collapse leaving the remainder (e.g., an outer shell) in the normal state.

For $A < A_{\min}$ one could, as already discussed, have C_A metastable with $\tau_A^{(C)} \gtrsim \tau_{\text{obs}}$ if A is not too small. For quite small A, the lifetime $\tau_A^{(C)}$ might become quite small corresponding to relatively short-lived multibaryon "resonant" states.

IV. PROPERTIES OF COLLAPSED NUCLEI

Although the properties of C_A are quite speculative it is important to discuss them so as to have a guide to the observational possibilities. We use the two types of models mentioned in the Introduction.

Quite independently of a specific model and simply because C_A is highly dense hadronic matter, one could have $B_A(C) \gg B_A(N)$ even for A only moderately larger than $A_{\min}$. Thus the binding energy per nucleon $b_C = B_A(C)/A$ could perhaps be hundreds of MeV and possibly even comparable with M_N. To avoid negative masses $b_C \leq M_N$ is required. For the constant-radius models, b_C may increase quite fast with A, with the bizarre possibility that the total mass M_C could eventually decrease with A, e.g., $M_C \to 0$ as $A \to \infty$. Clearly a large range of masses $0 < M_C < AM_N$ is possible. If $M_C \ll AM_N$, then collapse would give Q values comparable with the rest mass of N_A.

Nucleon model. This is a special case of the baryon model and assumes the constituents are neutrons and protons; nonrelativistically one effectively assumes $H_A(C) = H_A(N)$. The strangeness $S = 0$; for even A, a spin and parity $J^P = 0^+$ seems plausible, whereas for odd A, in a single-particle version, J^P depends on the partly filled orbits. For a Fermi-gas version, with equal numbers of neutrons and protons $N = Z$, and with $R_C \approx 0.5$ F, $A \approx 40$, one has a Fermi momentum $k_F \approx 11$ F^{-1} and an average kinetic energy per nucleon of $\bar{T} \approx 850$ MeV. It is noteworthy that relativistic effects reduce $\bar{T}$ and thus favor the collapsed state relative to the normal one. Thus one has $\bar{T}/\bar{T}$(nonrelativistic) $= X(y) \approx 0.6$ with $y = \hbar k_F / M_N c \approx 2.3$.[8]

The ground-state composition, for given A, is equivalent to determining the neutron excess, i.e., $-T_3 = \frac{1}{2}(N - Z)$, and hence the charge $Q = Z = T_3 + \frac{1}{2}A$. As for ordinary nuclei, we assume T_3 is due to competition between the Coulomb energy E_Q and the symmetry energy $E_T \propto T_3^2$ (for not too large T_3). If, furthermore, E_T is assumed to have the same dependence on density as just its kinetic energy part, then one obtains $E_T/E_Q \propto X(y)/R$ and $T_3 \propto -R/X(y)$. Thus, as compared to N_A, the Coulomb energy is relatively ineffective in giving a neutron excess for C_A [e.g., $T_3(C_A)/T_3(N_A) \approx 0.16$ for $A \approx 100$, $R = R_C \approx 0.5$ F], and the nucleon model predicts a large positive charge $Q \approx \frac{1}{2}A$ for C_A.

General baryon model. For the nucleon model the Fermi energy (even with the relativistic reduction) is well above the threshold for producing other baryons and mesons ($T_F \approx 1250$ MeV for $R_C \approx 0.5$ F, $A \approx 40$). It is then favorable to transform nucleons into distinct baryons occupying the lowest (1*s*) state, and the nucleon model must be considered as unrealistic. We must therefore expect C_A to consist of a mixture of baryons and mesons, i.e., to be an "hadronic soup." We recall the similar considerations for neutron stars.[9] Again relativistic effects, now due to the possibility of creating particles, favor C_A.

We limit ourselves to baryons. If then the differences in the average potential energies of different baryons are small compared to the mass differences, then as a function of the baryon composition the binding energy will be determined mainly by the baryon masses and kinetic energies. As an example we fill the 1*s* state with the baryons (spin doublets) of the SU_3 octet in order of increasing mass and then similarly with the members (spin quadruplets) of the decimet. Generally, in contrast to the predictions of the nucleon model, Q and the hypercharge Y are now quite small (large negative strangeness S), and for complete multiplets $Q = Y = 0$. The octet, decimet, ... are complete for $A = 16$, $56, \ldots$. These could be magic numbers associated with enhanced stability – perhaps so much so that only magic (neutral) C_A exist.

Quark model. For the "naive" model,[10] C_A is a composite of $3A$ (nonrelativistic) quarks. For parastatistics (≤ 3 quarks in each state) the orbits, in a single-particle version, are filled successively as A increases. For equal numbers of the three kinds of quarks, i.e., $N_{\mathfrak{N}} = N_{\mathcal{P}} = N_\lambda$, one has $Q = Y = 0$ ($S = -A$) and plausibly $J^P = 0^+$ for even A. One now expects two "symmetry" energies proportional to $T_3{}^2$ and Y^2, respectively $[T_3 = \frac{1}{2}(N_{\mathcal{P}} - N_{\mathfrak{N}}),\ Y = \frac{1}{3}(N_{\mathcal{P}} + N_{\mathfrak{N}} - 2N_\lambda)]$. Since $Q = 0$ for equal numbers, the "driving force" giving differences is now not the Coulomb energy but could be the mass difference $m_\lambda - m_{\mathfrak{N}}$, if $m_\lambda > m_{\mathcal{P}} = m_{\mathfrak{N}} = m_N$ (potential independent of the quark type). This favors an excess of nonstrange quarks and would give (small) positive Y and Q for large A. Since the quark model is a particular implementation of SU_3, it is perhaps not surprising that it gives similar predictions to the (SU_3) baryon model: in particular, *small positive or zero Q and Y.*

V. OBSERVATION OF C_A AND INTERACTIONS WITH ORDINARY MATTER

For values of A larger than but close to $A_{\min}$ one should not entirely exclude the possibility that $\tau_A^{(N)}$ may be just observable, giving energetic spontaneous "disappearances" of nuclei.

If C_A is charged (and also if neutral, but with $J \geq \frac{1}{2}$ and with electromagnetic moments) it will give ionizing tracks. Thus one could look for anomalous cosmic-ray tracks which are not identifiable with known nuclei; in particular we recall that both the general hadron and quark models suggest small positive charge and hypercharge with a large range of possible masses. For anti-collapsed matter the charges are reversed. Positive C_A will give $C_A e^-$ atoms and molecules with anomalous spectra – perhaps detectable in stellar spectra. Stable $C_A e^-$ atoms or molecules could be embedded in ordinary matter and one could search for anomalous masses and e/m values. The problems of detecting C_A would be similar to those for quarks[10]; indeed, fractionally charged C_A should also be envisioned. The observation of neutral C_A would be much more difficult than if it were charged; and one should consider the possibility that only neutral C_A exist. Observation will then depend on the strong interactions between C_A and N_A which we now discuss.

Perhaps the most characteristic and dramatic property of C_A is as *a source or sink of baryons*. Very energetic (e.g., cosmic ray) C_A incident on N_A could give multiple ($\leq A$-fold) baryon production – i.e., "ionization" – perhaps in the form of jets. Collapse of N_A (perhaps accelerated under extreme conditions as discussed below) and "radiative" nucleon capture (see below) imply that C_A is effectively a baryon sink giving *apparent* violation of baryon-number conservation.

Inelastic excitation of (cosmic ray) C_A followed by decay back to the ground state could occur (e.g., $C_A + p \to C_A^* +$ mesons, etc; $C_A^* \to C_A +$ mesons, etc.) with net production of mesons, γ rays, etc. If C_A is charged, this would greatly help to identify "ionizational" and inelastic collisions. Interactions of neutral C_A might be difficult to distinguish from those of ordinary neutrals. Even quite large amounts of C_A could presumably escape ready detection, especially if C_A is neutral and/or resides in inaccessible places (see below).

$C_A N_A$ interaction. At moderate energies ($\approx 10^2 - 10^3$ MeV) the $C_A N$ interaction (N = nucleon) is expected to be predominantly real and repulsive with range about R_C, since a large reflectivity will result from the large abrupt change in the effective $C_A N$ potential at R_C.[11] $C_A N$ scattering will then be predominantly (hard-sphere) elastic with a small total cross section $\lesssim 10$ mb. Slight transmission could give the very interesting possibility of "radiative" nucleon capture: $C_A + N \to C_{A+1} +$ mesons, etc., with perhaps Q values of several hundred MeV. Such capture gives a possible way of obser-

ving *neutral* C_A present in ordinary matter.

At very low energies (≲50 MeV) an attractive tail extending beyond R_C could become effective with the possibility of a *net* attractive interaction perhaps even sufficient to bind C_AN or $C_AN_{A'}$ (e.g., $C_A\mathrm{He}^4$). Such a tail would arise from meson exchange resulting from an effective C_A-meson Yukawa vertex (coupling constant g_C). If $J^P(C_A) = 0^+$ then exchange of a 0^+ meson is expected to dominate without any long-range one-pion-exchange contribution. The complexity of C_A could imply a small g_C, in which case a bound state is unlikely. If, on the other hand, a 0^+ meson is approximately universally coupled to the baryon charge, then g_C could be large and C_AN could then be bound. Even if unbound, the interaction could still bind C_A to a heavier nucleus (since for a given potential strength the binding is greater for larger masses and for larger radii of the effective $C_AN_{A'}$ potential). The possibility of $C_AN_{A'}$ compounds should certainly be considered. These would give anomalous masses, e/m ratios, and spectra, *even for neutral* C_A, but might be only metastable because of "radiative" capture by C_A of nucleons in $N_{A'}$.

VI. ASTROPHYSICAL CONSEQUENCES

Collapsed nuclei may have been copiously produced in the initial extremely hot and dense stages of the universe, and also later under extreme conditions. Subsequently it may separate from ordinary matter, e.g., by gravitational stratification or conversion of contiguous N_A into C_A through "radiative" capture. Decay of N_A during the lifetime of the universe would give only very small amounts of C_A, since $\tau_A^{(N)} > 10^{14}\ \tau(\mathrm{universe})$ and since only comparatively rare N_A with $A \gtrsim 20$ will be relevant. It is therefore possible that C_A may exist on a large scale: (1) diffused in space (galactic and intergalactic) where it could interact "ionizationally" or inelastically with cosmic rays; (2) condensed mainly on its own, perhaps as peculiar very compact massive black (?) objects; (3) in association with ordinary matter. There are in fact indications that much of the mass of the universe as well as of individual galaxies is unaccounted for.

Neutral C_A (no electrons) in bulk would be much denser than ordinary matter and would gravitate to the center of massive bodies. Thus the inner core of planets and stars might contain appreciable amounts of C_A which have perhaps been partially acquired by accretion. Anomalously dense planetary central cores are thus an interesting possibility. Energy (heat) could be produced as a result of "radiative" capture of N_A by C_A which is gravitating to the core, or at the boundary of a central accumulation of C_A which is perhaps associated with inner cores of planets. There is thus the bizarre possibility of celestial bodies being slowly "eaten up" and converted into collapsed matter.

A very interesting possibility is that the collapse of N_A may be greatly accelerated under extreme conditions and thus provide a source of energy which could be comparable with the rest mass. Thus for sufficiently dense massive bodies, the saturation barrier could be squeezed sufficiently for rapid collapse to occur. This might be expected to proceed catastrophically (and irreversibly) at densities roughly an order of magnitude larger than that of normal nuclear densities, corresponding to the collapse of nuclear clusters with A not too much above A_{min}, i.e., when the radius of clusters with $A \approx A_{\mathrm{min}}$ becomes comparable to R_C. This is then a possible source of large energies for bodies capable of collapse into neutron stars[9] with large central densities or into a "black hole".[12] For the latter an interesting possibility is that nuclear collapse might occur before the gravitational horizon is reached. In such cases a large fraction of the rest mass could be radiated away, whereas this seems difficult for gravitational collapse into a black hole for which the "available" energy is to a large extent effectively trapped by the strong gravitational fields.[12]

Also, quasars,[13] the positive energy of galaxies as well as intense activity associated with some galaxies and galactic nuclei,[14] and gravitational radiation from the galactic center[15] (perhaps $10^2 - 10^3$ solar masses per year) indicate tremendous sources of energy. So far these are far from convincingly explained, and nuclear collapse is an interesting possibility which should be considered.

VII. CONCLUSION

Our main point is that the existence of collapsed nuclei C_A of lower energy than normal nuclei N_A need not be in conflict with observations if N_A are long-lived isomers with respect to collapse. This is possible because of the existence of a "saturation" barrier between C_A and N_A, and penetrability estimates indicate that sufficiently long lifetimes (≳10^{24} yr) are possible for moderate values of $A \gtrsim 20$.

Although the properties of C_A – if they exist – are quite speculative, our discussion of the baryon and quark models nevertheless serves to show that C_A with small positive charges and hypercharges should be considered and, in particular, also neutral C_A. Thus one could look for anomalous nuclear masses, e/m ratios, spectra, and cosmic-ray tracks and events consistent with such charges and with a large range of possible masses, including quite small ones, since the binding energy of C_A could be comparable to the N_A rest mass. The possibility of artificially producing C_A, e.g., by heavy-ion collisions, seems remote. Even if large enough energies, needed to surmount the saturation barrier (of the order of 1 GeV for a combined $A \approx 40$), are available, the probability of forming a collapsed state, corresponding to a very specific collective mode, is expected to be negligibly small.

The most characteristic property of C_A is as an effective source and, especially, a sink of baryons, although there is of course no formal violation of baryon-number conservation. As a result one could have characteristic phenomena, such as multiple baryon production or " radiative" nucleon capture by C_A.

Large quantities of C_A could conceivably exist in the universe, but could quite plausibly have escaped detection because of the inaccessibility of C_A. A fascinating possibility is that the collapse of normal nuclei may be greatly accelerated in the dense interiors of massive bodies in the final stage of evolution and may provide a source of energy comparable with the rest mass.

I am indebted to many colleagues at Oxford and elsewhere for their helpful criticism and comments.

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*Research supported in part by the U.K. Science Research Council and by the U.S. Atomic Energy Commission.

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