On the Possibility of Electric Dipole Moments for Elementary Particles and Nuclei

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IT is generally assumed on the basis of some suggestive theoretical symmetry arguments[1] that nuclei and elementary particles can have no electric dipole moments. It is the purpose of this note to point out that although these theoretical arguments are valid when applied to molecular and atomic moments whose electromagnetic origin is well understood, their extension to nuclei and elementary particles rests on assumptions not yet tested.

One form of the argument against the possibility of an electric dipole moment of a nucleon or similar particle is that the dipole's orientation must be completely specified by the orientation of the angular momentum which, however, is an axial vector specifying a direction of circulation, not a direction of displacement as would be required to obtain an electric dipole moment from electrical charges. On the other hand, if the nucleon should spend part of its time asymmetrically dissociated into opposite magnetic poles of the type that Dirac[2] has shown to be theoretically possible, a circulation of these magnetic poles could give rise to an electric dipole moment. To forestall a possible objection we may remark that this electric dipole would be a polar vector, being the product of the angular momentum (an axial vector) and the magnetic pole strength, which is a pseudoscalar in conformity with the usual convention that electric charge is a simple scalar.

The argument against electric dipoles, in another form, raises directly the question of parity. A nucleon with an electric dipole moment would show an asymmetry between left- and right-handed coordinate systems; in one system the dipole moment would be parallel to the angular momentum and in the other, antiparallel. But there is no compelling reason for excluding this possibility. It would not be the only asymmetry of particles of ordinary experimence, which already exhibit conspicuous asymmetry in respect to electric charge. Although magnetic poles were used above as an illustration of a particular mechanism by which a nuclear electric dipole could arise, this is, of course, not the only possibility.

The question of the possible existence of an electric dipole moment of a nucleus or of an elementary particle in view of the above becomes a purely experimental matter. The evidence from most past experiments on molecules, atoms, nucleons, and elementary particles is not as conclusive as one might suppose. Most past experiments are in fact very insensitive to the effects of a nuclear electric dipole, because of the smallness of the electric field at the position of a charged nucleus or the antisymmetric nature of the electric dipole potential. We have analyzed a number of experiments including conversion of ortho- to parahydrogen, depolarization of neutron beams, ionization by neutrons, relaxation times of nuclei in liquids, nuclear scattering of neutrons, hyperfine structure studies, the Lamb-Retherford experiment, and the experiments on the interaction of electrons and neutrons. Non-scattering experiments on charged nuclei are particularly insensitive to the existence of an electric dipole moment and even the most favorable would not have revealed an electric dipole moment smaller than the charge of the electron multiplied by a distance D less than 10^{-13} cm. The scattering experiments[3,4] to detect an electron-neutron interaction are by far the most sensitive; the results of Havens, Rabi, and Rainwater[3] would correspond to a D of 3×10^{-18} cm if they were due to an electric dipole moment.

We are now undertaking, in collaboration with Mr. James H. Smith, an experiment which should directly measure the electric dipole moment of the neutron if it has a value of D of approximately the above magnitude. The experiment will utilize a neutron beam magnetic resonance[5] apparatus of high resolution[6] to detect a possible shift of the neutron precession frequency upon the application of a strong electric field.

The authors wish to thank Mr. Smith for suggesting an important correction to our original calculation on the neutron-electron interaction experiment.

[1] A typical argument is given by H. A. Bethe, *Elementary Nuclear Theory* (John Wiley and Sons, Inc., New York).
[2] P. A. M. Dirac, Phys. Rev. **74**, 817 (1948).
[3] Havens, Rabi, and Rainwater, Phys. Rev. **72**, 634 (1947).
[4] E. Fermi and L. Marshall, Phys. Rev. **72**, 1139 (1947).
[5] L. W. Alvarez and F. Bloch, Phys. Rev. **57**, 111 (1940).
[6] N. F. Ramsey, Phys. Rev. **76**, 996 (1949).

Supernovae*

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SUPERNOVAE of type I are characterized by: (a) a high intensity maximum of 20 to 30 days duration; (b) an exponential tail to the light curve of half-life 55 days ($\Delta m=0.0137 \pm0.0012$ magnitudes per day;[1] (c) an integrated visual light emission of nearly 10^{49} ergs;[1] (d) a residual gaseous shell of low hydrogen content expanding at a velocity[2] of 1300 km/sec. and radiating 10^{36} ergs/sec. visible light about 900 years later.[3]

These characteristics may be accounted for by the following proposed mechanism. The original star, of mass many times the sun, e.g., $15M_\odot$, undergoes gravitational contraction after burning its hydrogen. As the contraction progresses the central temperature will rise until a new reaction occurs. At a temperature of 2 to 3×10^9 °C a second-order endothermic reaction will occur between alpha-particles

$$2\alpha\rightarrow Be^7+n,\quad Q=-18.6 \text{ Mev}.$$

This reaction absorbs energy at the center of the star, permitting rapid gravitational collapse. The reaction rate can be calculated by methods of simple chemical kinetics since barrier penetration is a negligible correction at an energy of 19 Mev.

$$Z=N^2r^2(4\pi kT/m)^{\frac{1}{2}}e^{-(Q/2kT)},$$

where Z is the number of processes per second cm^3; N is the number of particles per cm^3; r and m are the radius and mass of the alpha-particle (1.6×10^{-13} cm and 6.6×10^{-24} g); Q is the reaction threshold; k is the Boltzman constant and T is the temperature. It may be noted that the reaction velocity per unit volume increases as the square of the helium concentration and exponentially with the temperature. The reaction will therefore accelerate under conditions of gravitational collapse, so that the star may collapse in a time approaching free fall.

The reaction will proceed until there are sufficient concentrations of the reaction products to produce the reverse reaction. The expression at equilibrium may be given

$$K=[Be^7][n]/[He]^2,$$

where the entries denote atomic concentrations per unit volume. Since neutrons will be absorbed rapidly in a system containing

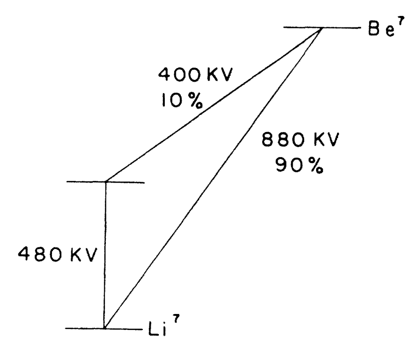

FIG. 1. Decay scheme of Be^7.