Formation of the Solar System by the Rotational Fission of a Star: the Fission Being Initiated by a Passing Second Star

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It is well known that a gravitating mass revolving about a star of the same uniform density cannot be in equilibrium if it is nearer to the star than 2.4 times the star's radius (Roche's limit). Investigation shows that the actual limit of stability extends indefinitely beyond the Roche limit if the rotational velocity of the gravitating mass approaches its critical fission value. This effective limit of stability R is given by

$$R=2.3B\left[\frac{\rho_s}{\rho_e(1-(\omega_e/\omega_{ec})^2)}\right]^{\frac{1}{3}},$$

where ρ_s and ρ_e are the densities of the star and rotating mass, respectively, B is the mean radius of the combined masses, while ω_e/ω_{ec} is the ratio of the actual to critical angular velocities for the rotating mass. Stars, passing well inside this limit, will be disrupted by the superposed tidal forces even though their angular velocity is notably below the critical value. Thus, rapidly rotating stars break up by fission preferentially in the vicinity of another star.

Assuming that the rapidly rotating star and a second star approach each other with velocities slightly exceeding their parabolic value and assuming various values for the distance of closest approach and the direction and magnitude of the axial rotation, it has been found by graphical means that after the approach (a) the stars may separate without permanent change; (b) the rotating star may divide by fission forming a binary star; (c) the rotating star may divide by fission, the nearer component being captured by the second star and the outer component proceeding as a single star; (d) the rotating star may divide by fission and both components be captured. One component with the second star forms a close binary while the other describes an open eccentric orbit about the other two.

The third possibility may be of importance in describing the origin of the solar system. Consider a rapidly rotating star which approaches another star and suppose that the angular velocities of rotation and revolution have the same direction. Suppose further that it rotates with an angular velocity somewhat less than, but approximating, its critical value. Now as this rotating star approaches the second star they are both grossly deformed by tidal forces and some of the orbital energy is utilized to separate the components and to change their angular velocity. Tidal forces acting in conjunction with the centrifugal forces cause the star to break up and simultaneously produce zones of instability on the inner and outer faces of the rotating star. Condensed masses of planetary size from the outermost zones leave the surface of the component star because they possess too much momentum for stability, while masses from the inner face leave it because they are deficient in momentum. Tidal forces between the stellar companions and the second star reduce the angular velocity of rotation. The resulting slowly rotating outer component finally proceeds to infinity accompanied by two different families of satellites all marked, as a result of their birth process, by definite asymmetries. The details of planetary formation follow those suggested in earlier papers.[1] No serious inconsistency of energy or momentum has emerged as a result of the calculations and it appears that a stellar encounter of the type considered will produce a distribution of masses remarkably like the solar system.

Because close encounters are highly improbable in the present disperse universe, it seems necessary to assume that stars, ages ago, were very close together. All other leading theories, except that referenced above, are similarly embarrassed.

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[1] Ross Gunn, Phys. Rev. **39**, 130, 311 (1932).

Fission of Uranium by Alpha-Particles

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Fission of uranium has been produced by neutrons, deuterons and gamma-rays. The 60″ cyclotron of the Crocker Radiation Laboratory with its 32-Mev alpha-particles afforded the possibility of trying to produce fission by alpha-bombardment of uranium.

A layer of ammonium uranate, a few millimeters thick was bombarded with a beam of several milliamperes intensity of 32-Mev alpha-particles for about one minute and was afterwards tested chemically for some of the characteristic fission products of uranium. The following were found: iodine (54 minutes), iodine (3.4 hours), I^{133} (22 hours), I^{131} (8 days). In some cases we found also tellurium members of the same chains.

In order to check that the activation was not due to secondary neutrons, both faces of the thick uranium target were tested. The face not directly exposed to the beam showed practically no activity. In order to rule out also the possibility of a deuteron contamination of the beam itself, it was checked that the ratio between the activity of 93^{239} and fission products was less, by order of magnitude, than the same ratio under deuteron bombardment. The 93 activity itself was possibly due to a small residual deuteron contamination of the beam or to secondary neutrons.

We looked also for possible delayed fission by bringing the sample a few minutes after the end of the bombardment in front of an ionization chamber connected to a linear amplifier. No big kicks due to fission were observed.

The Gamow barrier for alpha-particles colliding with uranium is estimated to be almost 30 Mev. However, the transparency of the barrier for particles up to 4 or 5 Mev below the top of the barrier is still large enough to allow them to penetrate inside the nucleus with a large probability. If these estimates are correct, the formation of a compound nucleus by uranium and alpha-particles would have a large cross section even for energies somewhat below 25 Mev.

The excitation energy of the compound nucleus is less than the kinetic energy of the alpha-particle because at the top of the periodic system the process of emitting alpha-particles from the nucleus is exothermic. On account of this fact the excitation energy of the compound nucleus is probably from 5 to 10 Mev less than the kinetic energy of the alpha-particle. This leaves an excitation which may vary according to the energy of the primary particle from 15 to 27 Mev, and is therefore amply sufficient to produce the fission of the compound nucleus. Indeed it is so large that 2 or 3 neutrons may be evaporated, still leaving a sufficient energy available for the fission.

In conclusion, we wish to thank Professor E. O. Lawrence for his interest in this work, the Research Corporation for financial support and the Hitchcock Foundation for providing the opportunity for one of us to visit the Radiation Laboratory.

Excitation of Gamma-Rays by Fast Neutrons of Different Energy

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ATOMIC cross sections of Al, Si, Fe, Co, Cu, Ag, Cd and Pb for gamma-ray excitation by fast neutrons of different energies from 2.25 to 2.90 Mev were determined. The neutron source used was a *D–D* type with 200-kv acceleration, and the neutron energy was varied by changing the angle φ between the paths of the neutrons and the deuterons. The gamma-rays emitted were measured by a thin-wall Geiger-Müller counter surrounded by a sheet of lead 1 mm in thickness.

In a *D–D* neutron source, not only the energy but also the number of neutrons emitted depends on φ. Therefore, the number was measured by an ionization chamber filled with a mixture of hydrogen and nitrogen to 14.1 atmospheres pressure, the purpose of adding nitrogen being to make the range of recoil protons short compared with the dimension of the chamber.

The results obtained for the cross sections σ_γ are shown in Fig. 1, where the neutron energy was calculated by taking $Q=3.32$ Mev[1] and assuming the deuteron beam to be 40 percent atomic and 60 percent molecular and that the heavy water ice target was thick. General features of the curves for Al, Fe, Cu and Cd agree qualitatively with the results of H. Kallmann and E. Kuhn,[2] but precise comparison cannot be made, as they have made measurements only at three different values of neutron energy. In the present experiment, anomalies were observed in most cases. The absolute magnitude of the cross section for Cu at 90° ($E_n=2.52$ Mev) was estimated to be 2×10^{-24} cm^2 by calculating the absolute number of neutrons incident on the measuring system from the absolute value of the ionization current in the chamber and by taking the efficiency of the counter for the gamma-rays to be one percent.[3] This absolute value of σ_γ is about seven times greater than the value estimated by H. Aoki,[4] and is about 80 percent of the total cross section σ_t. As the mean number of gamma-ray quanta emitted per one inelastic collision of a *D–D* neutron is considered to be not so large (perhaps smaller than two, because of the comparatively low excitation of the residual nucleus), σ_γ may be only a little larger than the cross section of inelastic collision σ_{inelast}. From these considerations and the above results, it may be said that for nuclei of medium weight such as Fe, Co, Cu, Ag or Cd a considerable part of the scattering of *D–D* neutrons is inelastic.

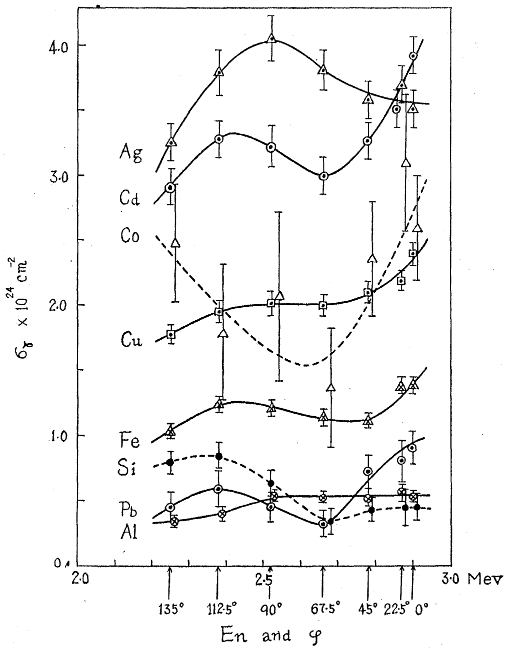

FIG. 1. Energy cross section curves.

H. Aoki[5] has observed many anomalies in the total cross sections of Si, Al, Fe, Pb, etc. The positions of anomalies observed in σ_γ lie near those of σ_t (when we recalculate E_n by taking $Q=3.32$ Mev), and the magnitudes of the variations are almost equal in both cases; especially for Pb the variations of σ_γ and of σ_t are very similar in the positions of maximum and minimum and in the magnitude. At any rate, the anomalies in σ_t observed by H. Aoki or M. R. MacPhail[6] cannot be considered to be entirely due to elastic scatterings.

A detailed report will be published in the *Proceedings of the Physico-Mathematical Society of Japan.*

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[1] L. G. Bonner, Nature **143**, 681 (1939).
[2] H. Kallmann and E. Kuhn, Naturwiss. **26**, 107 (1938).
[3] F. Norling, Phys. Rev. **58**, 277 (1940).
[4] H. Aoki, Proc. Phys.-Math. Soc. Japan **19**, 369 (1937).
[5] H. Aoki, Proc. Phys.-Math. Soc. Japan **21**, 232 (1939).
[6] M. R. MacPhail, Phys. Rev. **57**, 669 (1940).