Anomalon Production by Impulsive Excitation in Relativistic Heavy-Ion Collisions

B. F. Bayman, P. J. Ellis, S. Fricke, and Y. C. Tang
School of Physics, University of Minnesota, Minneapolis, Minnesota 55455

(Received 21 May 1984)

We have calculated the excitation energies of projectile fragments produced when relativistic projectiles make peripheral collisions with target nuclei. We find that the excitation energy of the fragment is much greater when the target nucleus is relatively heavy (such as Ag or Br) than when it is light (C or O). This could explain the difference between the results of anomalon searches in nuclear emulsion and plastic detectors.

PACS numbers: 25.70.Np

Measurements in nuclear emulsions have shown that when relativistic nuclei (the "primary" projectiles) collide with emulsion nuclei, some of the resulting projectile fragments have anomalously short mean free paths (mfp), and thus anomalously large reaction cross sections.[1-4] These fragments are called anomalons.

In addition, four experiments have recently been reported in which projectile fragments have been created by collisions of relativistic nuclei with nuclei in plastic detectors. In two of these experiments,[5,6] 1.8*A*-GeV ^{40}Ar and ^{56}Fe beams interacted with Lucite plastic, and the Cherenkov radiation from the fragments was detected electronically. Neither experiment found statistically significant evidence for anomalons. In the other two experiments, tracks were observed when 1.8*A*-GeV ^{40}Ar beams interacted with CR-39 plastic. Heinrich *et al.*[7] studied 6444 fragment interactions and found, in agreement with Lucite experiments, no evidence for anomalons. However, Tincknell, Price, and Perlmutter[8] found anomalon effects in a much smaller sample (612 fragment interactions). Thus, while there is some contradiction among the plastic data, it seems clear that projectile fragments with anomalously short mfp are more likely to be produced by interactions in nuclear emulsions[9] than by interactions in plastics. The purpose of this communication is to show that this result is consistent with the impulse mechanism we proposed for anomalon production several years ago.[10] The main point is that the impulse mechanism produces anomalons more copiously when projectile nuclei interact with heavy target nuclei, such as Ag or Br in emulsion, than with light target nuclei, as H, C, or O in plastic.

In our model,[10] anomalons are nuclei excited to their highly deformed quasimolecular states.[11] By use of simple arguments given by Harvey,[12] one can estimate that these long-lived states should occur in nuclear systems with Z or N larger than 14. In fact, such states in ^{32}S have already been convincingly shown to exist in the excitation-energy region above 7 MeV by Schultheis and Schultheis,[13] who performed a rather elaborate calculation employing the microscopic α-cluster model.[14]

We have proposed[10] the following mechanism for the formation of projectile fragments in quasimolecular states. In a peripheral collision between projectile and target nuclei, a few nucleons or nucleon clusters are ejected and the remaining projectile fragment feels a short-range attractive nuclear force and a longer-range repulsive Coulomb force. Because of the high relative speed of the target and projectile, the nucleus does not have sufficient time to respond significantly during the encounter. Thus the effect on the projectile fragment of these forces is an impulsive one. The net result of the nuclear and Coulomb components of this impulse is the excitation of the projectile fragment to a state of transverse oscillation relative to its mass center. This oscillation may carry the fragment into the deformation region associated with quasimolecular states.

An impulsive collision cannot change the fragment potential energy, since the fragment does not have time to deform appreciably during the impulse. Thus the excitation energy of the fragment will equal the change in its internal kinetic energy. To estimate this, we calculate the impulse (momentum change) at each point in the fragment as a result of the collision. The force felt at each fragment point is obtained by folding the gradient of a nucleon-nucleon interaction over the density of the stationary target nucleus. We use an interaction that has been proven successful in folding derivations of optical potentials.[15] The part of this interaction mainly responsible for the fragment excitation is the direct potential V_d, given by

$$V_d = -V_0 \exp(-Kr^2) \qquad (1)$$

with $V_0 = 22.23$ MeV and $K = 0.46$ fm^{-2}. The density distributions of the various nuclei involved are chosen to have Woods-Saxon forms, with the diffuseness parameter a assumed to be 0.55 fm. The values of the radius parameter R are then adjusted such that the resultant matter rms radii are equal to 2.31, 2.60, 3.15, 4.15, and 4.54 fm for ^{12}C, ^{16}O, ^{32}S, ^{80}Br, and ^{108}Ag, respectively.[16] The fragment and the target nucleus are assumed to pass each other at constant velocity, with a specified impact parameter b.

In Fig. 1, we illustrate, in the case of ^{32}S projectiles at 1A GeV, the excitation energy E^* of ^{32}S as a function of the impact parameter b.[17] To evaluate the relative effectiveness of the various target nuclei in exciting ^{32}S quasimolecular states, we consider the E^* value at an impact parameter b_c for grazing interaction, defined as

$$b_c = R_p + R_t - 2a, \tag{2}$$

where R_p and R_t represent the equivalent uniform-density radii for the projectile and target nuclei, respectively. As is seen from this figure, the values of E^* for grazing collisions (indicated by arrows) are equal to 5.1, 5.4, 15.7, and 17.9 MeV when the target nuclei are C, O, Br, and Ag, respectively. The important point to note here is that, at the grazing distances, the excitation energies caused by the interactions with the heavy elements Br and Ag are about 3 times larger than those caused by the interactions with the light elements C and O.

Since quasimolecular states are expected to occur in the excitation-energy region above 7 MeV, it is clear that the range of impact-parameter values for effective excitation to quasimolecular states is much larger when the target nucleus is a heavy element than when the target nucleus is a light element. This suggests that the production of anomalons is mainly effected by peripheral interactions with the heavy nuclei in the emulsion. Interactions with light nuclei may have some significance, but the significance is very likely minor.

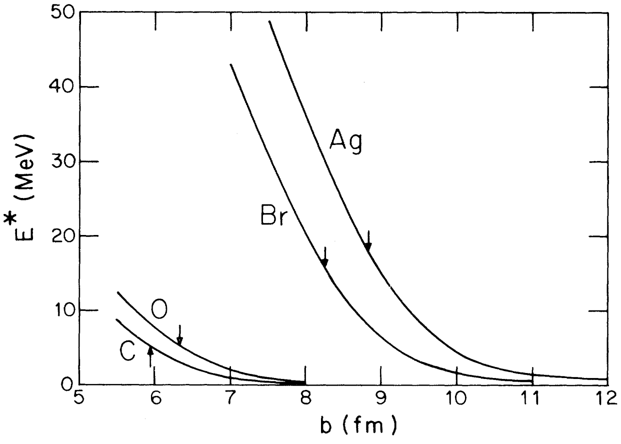

FIG. 1. Excitation energy E^* of ^{32}S as a function of the impact parameter b for various target nuclei.

The considerations above suggest that anomalons are predominantly produced in collisions with heavy target nuclei. Future anomalon searches would therefore be more productive if they were carried out in nuclear emulsions or, as has been suggested by Heinrich *et al.*,[7] by use of plastic detectors interleaved with heavy-element foils. Also, the conjecture[18] that anomalons are quasimolecular states with Z or N larger than 14 implies that it would be advantageous to use beam particles heavier than the customary ^{40}Ar and ^{56}Fe nuclei, so as to produce more projectile fragments with larger Z values.

This research was supported in part by the U.S. Department of Energy under Contract No. DOE/DE-AC02-76 ER 10364.

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