thesis in the subpopulation of epiphyseal cartilage cells susceptible to this stimulation. This hypothesis is consistent with the mode of action of the pharmacological agents used to inhibit the EF effect and with evidence on the control of cell division in other systems.

The findings have further interesting implications. Tetrodotoxin-sensitive "channels" are usually characteristic of cells with fast-spreading action potentials (*26*). Our data suggest that membrane depolarization may play a role in the control of cell division in epiphyseal chondrocytes. The phenomenon may be related to the embryonic state of the tissue and has been suggested as a possible mechanism for the intercellular communication involved in morphogenesis (*27*).

Detailed knowledge of the charge distribution and dipole moments in cell membranes (*19*) and the propagation of EF's in electrolytes would probably add to the understanding of the precise nature of the electrical events experienced by the cells in our system. We have demonstrated that an external oscillating field applied to cartilage cells in suspension generates a perturbation that stimulates DNA synthesis, and that Ca^{2+} and Na^{+} fluxes are intimately related to the EF effect. Further studies should show if this phenomenon is involved in the mechanical modulation of bone growth. This information could be used to influence cell proliferation for therapeutic purposes.

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29. The EF was generated by two curved copper electrodes, 1.5 cm apart, cemented to the inner surface of a Plexiglas well and connected to a Hewlett Packard 6516A d-c power supply. Polypropylene (1 mm thick) capped test tubes (1.5 cm diameter) containing the cell suspension fitted snugly between the electrodes. The liquid level of the cell suspension and medium approximated the vertical height of the plates. The relative ambient humidity in the incubation mixture was 25 percent (at 37°C). The pulse shape was regulated by a Grass physiologic stimulator (model S4GR). In this study a rectangular-shaped pulse of 1166 volt/cm, 0.1 second on and 0.1 second off was used. The voltage alternated between 0 and 1750 volts. The rise time of the driving voltage was 1850 μsec.
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Motion of Enclosed Particles Around a Central Mass Point: Errors in the "Apples in a Spacecraft" Model

Alfvén (*1*) considered the motion of a number of inelastic particles ("apples") enclosed in a spacecraft in circular orbit around a central mass point. He concluded that the system tends toward a final state in which all particles are aligned on the circle described by the center of gravity of the spacecraft. This result was taken by Alfvén as evidence in favor of his hypothesis on the formation of "jet streams" (*2*).

Unfortunately, Alfvén's reasoning is incorrect and the final state of the system is in reality rather different from what he predicts. This conclusion has apparently escaped notice so far, and Alfvén's result continues to be cited uncritically (*3*). Thus it appears desirable to correct the record. For convenience I shall designate by "up" and "down" the directions away from and toward the central mass, respectively. Let r_0 be the radius of the orbit of the spacecraft's center of gravity, and a be the semimajor axis of the elliptical orbit of a particle. If a is less than r_0, that is, if the particle is, in the mean, "lower" than the spacecraft's center of gravity, its angular velocity is larger than that of the spacecraft. Thus after a while it will hit the front wall of the spacecraft. As a result, the particle loses energy and a decreases. (The mean velocity of the particle on its new orbit will be larger than before; this is the usual paradox of Newtonian mechanics, whereby an artificial satellite losing energy through friction with the atmosphere spirals down to Earth with increasing velocity.) There is then a new collision with the front wall, which decreases a further, and so on. On the other hand, the inelastic collisions tend to damp out the oscillations, that is, the deviations of the orbit from circularity. So we may expect the process to terminate with the particle lying motionless in the lowest point of the spacecraft. (For simplicity I assume, like Alfvén, that the spacecraft always turns the same side toward the central body.) This is a stable equilibrium position: the particle is held against the floor by a positive downward force, because the centrifugal force acting on it is less than the attraction of the central body. Conversely, a particle with a greater than r_0 rotates more slowly than the spacecraft, hits the back wall, gains energy and rises further, until it reaches the highest point of the spacecraft. Thus in the final state the particles are divided into two groups, one group lying on the floor and the other on the ceiling. This conclusion is not changed if mutual collisions of the particles are taken into account, or if some gas is present in the spacecraft.

Alfvén reached a different conclusion simply because he assumed, without justification, that the particles "will not be in permanent contact with the walls." This arbitrary assumption eliminates from the start the correct solution of the problem and leaves only the artificial solution where all particles are in the same circular orbit as the spacecraft's center of gravity, with $a = r_0$. This is actually a solution in a mathematical sense: a particle placed exactly in this orbit will remain there. But it is a physically meaningless solution because it corresponds to an unstable equilibrium: any deviation of a from the exact value r_0 will be amplified by collisions with the walls, and the particle will either fall to the floor or rise to the ceiling.

There is another error near the end of Alfvén's report, in the following passage: "Suppose that the mass of the spacecraft is much smaller than the mass of the particles and that their original common center of gravity were situated at an r larger than the center of gravity of the spacecraft. Then the particles would move more slowly than the spacecraft and would hit its backside wall, with the result that the spacecraft would be displaced outward." The last word should be replaced by "inward," because the spacecraft loses energy in the collisions. As a consequence, its center of gravity moves not toward the center of gravity of the particles but away from it.

In general, then, collisions tend to disperse the radii rather than to bring them together. If, as suggested by Alfvén, the "apples in a spacecraft" model is relevant to the hypothesis on the formation of "jet streams," then it appears to be in fact an argument against this hypothesis.

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Mutual collisions in a stream of particles moving approximately in parallel render the stream increasingly more diffuse. It was earlier believed that this tendency toward diffusion applied also to a stream of particles in Kepler orbits. This is not necessarily true because under certain conditions mutual collisions lead to a decrease in the spread of the orbital parameters, which may lead to the formation of a "jet stream." According to Baxter and Thompson (*1*), a stream of particles in Kepler orbits may exhibit a "negative diffusion."

When this point was clarified, I thought that the model criticized by Hénon (*2*) would be useful as a simple pedagogical illustration, not observing that the collisions between the "apples" and the spacecraft give the correct angular momentum only if the spacecraft spins with the angular velocity $-2w_K$. As the assumption of such a spin makes the model too complicated to be of any pedagogical value, I agree with Hénon that this model should not be used. However, Hénon's intimation that the model constitutes an argument against the jet stream hypothesis is not valid because the motivation for the jet stream concept has nothing to do with this model.

This does not mean that the theory of jet streams is in very good order. A number of numerical experiments have been done by Trulsen (*3*), Ip (*4*), and the Hénon-Brahic group (*5*). These experiments show that mutual collisions in a stream with an original distribution in the semimajor axis a, the eccentricity e, and the inclination i reduce the spread in i and e to zero but give only a limited decrease in the spread in a. The spread in a is not reduced to zero because the particles very rapidly reach orbits with $e = 0$, and, when they have done so, the decrease in a stops because the particles do not interact at all. However, this noninteraction is not fatal to the existence of jet streams because the model is too idealized. In reality, orbits with $e = 0$ do not exist because of perturbations, and, if the model is worked out under the condition that e should never be exactly zero, the particles will continue to interact, thus decreasing the spread in a which leads to the formation of a jet stream (*4*). Another effect produces a similar result: when applied to the cosmogonic problem, the injection of particles with $e = 1/3$ should occur during a long time, which means that e continues to have finite values (*6*).

Hence there are good reasons for believing that jet streams were important as an intermediate step in the formation of planets, satellites, and asteroids, and jet streams may also have possible applications to the origin of comets (*7*). On the other hand, it is not yet clear whether the present density in interplanetary space is sufficient to produce jet streams.

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