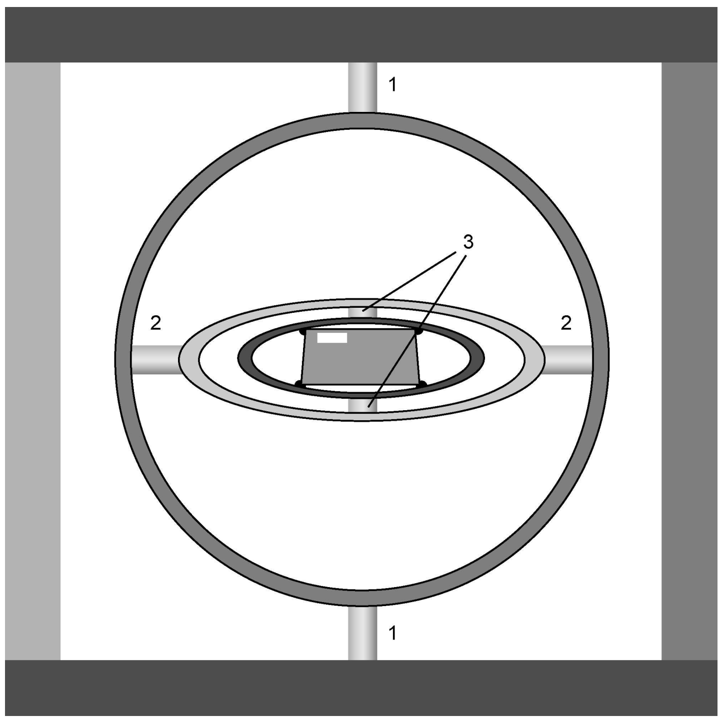

FIGURE 2.8 *A schematic representation of the gimbal system of a spacecraft guidance system. The outer rim represents the (presumably quite massive) structure of the vehicle. The cylinders connecting the rings to other structures represent nearly frictionless rotating bearings. The gray square in the middle is the inertial guidance system, which presumably is set to a particular orientation and is thereafter not supposed to change its direction.* (Image from NASA Apollo 15 Flight Journal transcripts at *www.hq.nasa.gov/office/pao/History/ap15fj/15solo_ops3.htm*, W. David Woods and Frank O'Brien.)

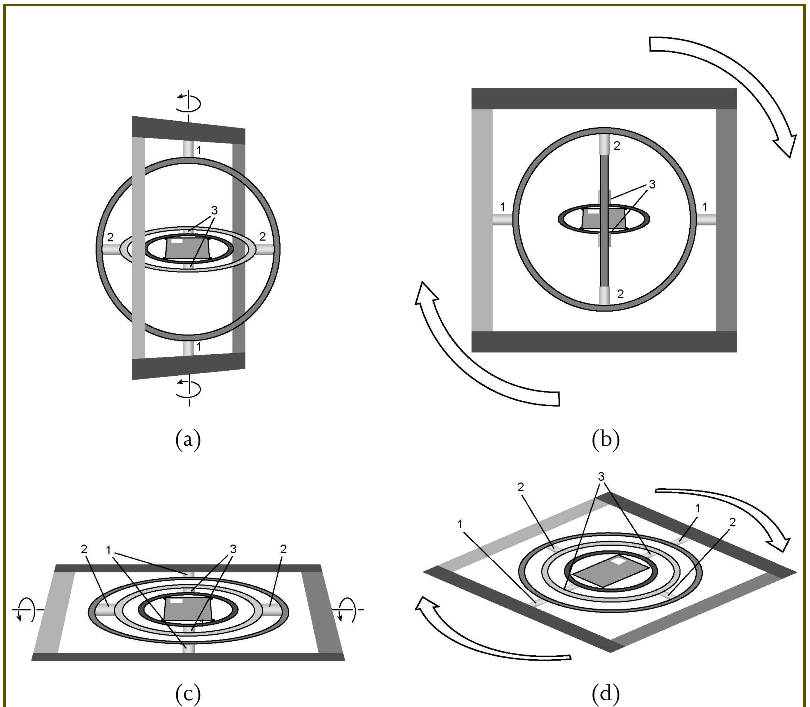

FIGURE 2.9 *How a spacecraft gets into gimbal lock. Starting from the initial configuration* (Figure 2.8), *we observe that each of the configurations a through c corresponds to rotations about a single axis. The 90-degree rotation about axis 2 in Figure 2.8 causes axes 1 and 3 to line up in c, losing a degree of freedom and potentially destroying the ability to further monitor the spacecraft's attitude. An external force causing rotation about the vertical axis in the bottom images will attempt to make the "locked" gyroscopes move with the spacecraft. A single gyroscope would simply flip in response to Newton's laws for torques. Multiple orthogonal gyroscopes such as those in the Lunar Module IMU would resist all torques and eventually cause disastrous damage to the spacecraft.* (Images from NASA Apollo 15 Flight Journal transcripts at *www.hq.nasa.gov/office/pao/History/ap15fj/15solo_ops3.htm*, W. David Woods and Frank O'Brien.)