INSTRUCTOR NOTES
Accelerating reference frames: The Foucault pendulum

Emphasis

This tutorial is the third of a series of three on accelerating reference frames. Students first analyze qualitatively the motion of a simple pendulum as observed in the frame of a rotating platform. They then extend their results to an Earthbound reference frame and discover the effect of the latitude of the pendulum on the rate of precession.

Prerequisites

It is strongly recommended that students have completed beforehand the other two tutorials on non-inertial frames: *Accelerating reference frames: Inertial "force" and local acceleration due to gravity* and *Accelerating reference frames: Rotating frames.* Prior lecture instruction on the Foucault pendulum, though, is not required; this tutorial can serve as an introduction to the topic.

TUTORIAL PRETEST

The pretest poses an open-ended task that probes student ideas about the Foucault pendulum without mentioning the term explicitly. Students are told that a very long pendulum oscillates along a plane running due north and south, and they are asked how they think the motion of the pendulum (in the absence of friction) would be different two hours later. Although some students may remember that the rotation of the Earth causes the plane of oscillation to precess, many may not recognize how the Earth's rotation and location (latitude) on the Earth affect the precession. For example, many students may incorrectly state that two hours later the plane of oscillation would rotate exactly 30° (2/24 of 360°) without taking latitude into account.

TUTORIAL SESSION

Equipment and handouts

Each group will need a whiteboard and set of markers, or a large sheet of paper. Each student will need a copy of the tutorial handout (no special handouts required).

Optional equipment: Each group may be provided a simple turntable and support apparatus with which to suspend a pendulum bob above the center of the turntable. This equipment can be very helpful in section II of the tutorial, in order to bolster the spatial reasoning skills of some students.

Discussion of tutorial worksheet

Section I: Pendulum observed in a rotating frame

The tutorial begins by giving students the opportunity to visualize and account for the precession of a "simplified" Foucault pendulum: a simple pendulum is observed from the frame of a rotating platform (without taking the Earth's rotation into account). Focusing on cases in which the period of rotation is much longer than the period of oscillation of the pendulum, students should be able to visualize that counter-clockwise rotations of the platform will result in clockwise precession of the pendulum (in the platform frame), which always cause the pendulum bob to "turn to the right." A follow-up question helps students recognize that reversing the rotation of the platform also reverses the direction of the precession. Students recognize in this case—a special case in which the angular velocity vector of the rotating frame is exactly parallel to the equilibrium orientation of the pendulum—the period of precession must be equal to the period of rotation of the platform.

Finally, students are guided to recognize that the Coriolis "force" is the only possible fictitious "force" responsible for the precession. At the checkpoint that concludes this section make sure students can use the Coriolis "force" and appropriate right-hand rules to correctly account for the "turning left or "turning right" of the pendulum as viewed in the platform frame. Successful completion of this checkpoint is crucial for students to make sense of a Foucault pendulum.

Section III: Pendulum observed on a rotating Earth

Students now extend the results they obtained in section I. In part A imagine a pendulum suspended from a location directly above the North Pole. Students should have little problem recognizing that their results from section I can directly account for the (clockwise) precession of the Foucault pendulum for this case.

In part B students continue by imagining the pendulum an unspecified northern latitude λ. They should readily determine that the precession is unchanged in direction, but it will likely be more difficult for them to explain why the precession frequency will be smaller than what it is at the North Pole. They are guided to think specifically about the horizontal component of the fictitious "force" (the Coriolis "force," which remains purposefully unnamed in the tutorial handout) responsible for the precession. The "hint" provided here should help students get started. Make sure that they consider both cases posed in part B—one with initial velocity northward, the other with initial velocity eastward—when explaining their logic. Students wrap up the tutorial by generalizing that the frequency of precession must be highest at the poles, that no precession occurs at the equator, and that the direction of precession must be counter-clockwise (not clockwise) in the southern hemisphere.

TUTORIAL HOMEWORK

The homework contains a variety of problems that require students to apply the ideas covered in tutorial both qualitatively and quantitatively. (In addition, some of the problems from the tutorial homework *Accelerating reference frames: Inertial "force" and local acceleration due to gravity* involve rotating frames and may be assigned as well.)

1. Having completed the tutorial, students should be able to provide a qualitative explanation linking the Coriolis "force" to the precession of a Foucault pendulum. Here students are asked to explain why the other fictitious "forces" (inertial, centrifugal, and transverse) may be ignored in the analysis of the Foucault pendulum.
2. Students reflect (perhaps more deeply than they did during the tutorial) on important qualitative aspects of the motion of the "simplified" Foucault pendulum from section I of the tutorial. (For instance, in the platform frame, does the pendulum ever pass through the center of the platform or not? Does the pendulum bob ever have an instantaneous velocity of zero?)
3. Students again revisit the "simplified" Foucault pendulum from section I of the tutorial, but more quantitatively. Having already identified the Coriolis "force" as causing the precession of the plane of oscillation of the pendulum, students determine the x'- and y'-components of the Coriolis "force" and then use those expressions to write down the x'- and y'-component equations of motion for the pendulum. Students then must explain in their own words how their equations of motion illustrate the appropriate direction (whether clockwise or counter-clockwise) for the precession of the pendulum.
4. Students extend their results from tutorial and from Problem 3 by now considering a Foucault pendulum at latitude λ on the Earth. They must recognize here that only the vertical component of angular velocity, of magnitude $\omega_E \sin \lambda$, affects the horizontal component of the Coriolis "force." On the basis of this result students should be able to deduce from the component equations of motion the correct direction of precession for each hemisphere. Furthermore, in comparing the equations of motion from this problem to those in Problem 3, students can infer that the plane of oscillation precesses with angular velocity $\omega_E \sin \lambda$ and thus with period (24hrs / $\sin \lambda$).
5. In this problem students apply both their qualitative results from the tutorial and their quantitative results from Problem 4.