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.* Also recommended are the tutorials *Simple harmonic motion* and *Harmonic motion in two dimensions.* However, prior lecture instruction is not required; this tutorial can be used to introduce the Foucault pendulum.

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, especially for those students with weak spatial reasoning skills.

Discussion of tutorial worksheet

Section I: Simple pendulum as an oscillator in two dimensions

The tutorial begins with a brief section in which students are guided to recognize that a simple pendulum undergoing small oscillations in a horizontal plane can be considered an isotropic oscillator. They are also asked to describe in words how to initiate the motion of the pendulum so that it oscillates along a single axis as opposed to along an elliptical path. (These questions cycle back to some of the basic concepts developed in *Harmonic motion in two dimensions*.)

Section II: Pendulum observed in a rotating frame

In order to help students visualize and account for the precession of a Foucault pendulum, this section provides the opportunity to consider a somewhat easier situation: observing a simple pendulum from the frame of a rotating platform (without taking the Earth's rotation into account). For the case in which the period of rotation is much greater 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 right." A follow-up question helps students recognize that reversing the rotation of the platform also reverses the direction of the precession. Students are guided to recognize that the Coreolis "force" is the only possible fictitious "force" responsible for the precession. Finally, students conclude that 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. The checkpoint at the end of this section is crucial in order to ensure students are in a position to make sense of a Foucault pendulum.

Section III: Pendulum observed on a rotating Earth

Students now extend the results they obtained in section II by imagining a pendulum suspended from (1) a location directly above the North Pole and then (2) a location at unspecified northern latitude l. Using an Earthbound coordinate system students are guided to recognize that their results from section II can be attributed directly to the Foucault pendulum at the North Pole. They are further guided to recognize that the rate of (clockwise) precession must decrease as smaller and smaller values of (northern) latitude are considered. Finally, students conclude that the rate of precession must be greatest 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. Students revisit the situation from tutorial in which a slowly oscillating pendulum is viewed in the reference frame of a rotating platform. Having already identified the Coreolis "force" as causing the precession of the plane of oscillation of the pendulum, students are guided to translate their qualitative results from tutorial into quantitative results: they determine the x'- and y'-components of the Coreolis "force" and then use those expressions to write down the x'- and y'-component equations of motion for the pendulum. Finally, students 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.

2. Students extend their results from tutorial and from Problem 1 by now considering a Foucault pendulum at latitude l on the Earth. They must recognize here that only the vertical component of angular velocity, of magnitude $w_E \sin l$, affects the horizontal component of the Coreolis "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 Problems 1 and 2, students can infer that the plane of oscillation precesses with angular velocity $w_E \sin l$ and thus with period (24hrs / sin l).

3. In this problem students apply both their qualitative results from the tutorial and their quantitative results from Problem 2.

4. Having completed the tutorial, students should be able to provide a qualitative explanation linking the Coreolis "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.