UAA's Foucault Pendulum

1 Introduction

The large pendulum in the Consortium Library is an example of a Foucault Pendulum. Any mass on the end of a string (the mass is called a 'bob') will swing back and forth, however a Foucault pendulum is very carefully constructed to produce simple, planar oscillations with no preferred direction. A Foucault pendulum is designed to demonstrate the very small dynamical effects induced by the rotation of the Earth.

2 History

A few hundred years ago, whether the Earth rotated or not was an important issue. Giordano Bruno taught that the Earth moved and he was burned alive in 1600 by Pope Clement VIII. Galileo was also charged with the same heresy in 1633 and, because he recanted, was sentenced to house arrest for the remainder of his life [1]. Over the next several decades the rotation of the Earth was gradually accepted by most astronomers—but experimental proof was lacking [2].

One way that people tried to observe the rotation of the Earth was by dropping balls. In 1679 Isaac Newton predicted that the rotation of the Earth would cause balls dropped from high towers to have a small, eastward deviation from vertical. Several attempts were made to observe this effect. However the deviation is so small that efforts to measure it were generally inconclusive [3].

In 1851 Jean Bernard Leon Foucault offered the first terrestrial proof that the Earth rotates. Foucault did not have a formal training in science but was more of a tinkerer. Foucault attached a 28 kilogram bob to the end of a 67 meter wire connected to the domed ceiling of the Pantheon in Paris. To start the bob moving without any small push sideways, he tied the bob off to the side with a small piece of thread and then burnt the thread. As the bob oscillated back and forth it traced a path in sand spread on the platform beneath it. The rotation of the earth caused the bob to not retrace its path exactly. Instead with each oscillation the bob slightly deviated to the right of the previous path, demonstrating that the platform was slowly rotating underneath the pendulum. The demonstration caught the imagination of the public and the experiment was soon repeated by others around the globe [4].

3 Science

To understand what the Foucault pendulum is demonstrating, let's imagine that we are standing with the pendulum at the North Pole. As seen by someone out in space (at rest

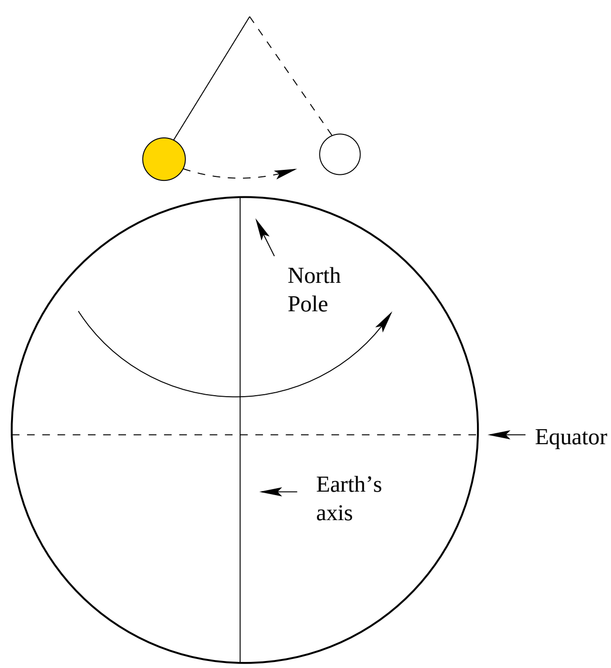

Figure 1: At the north pole, the plane of a pendulum's motion would appear to turn 360 degrees in 24 hours.

with respect to the distant stars), the pendulum swings back and forth in a plane whose direction does not change. This is an example of Newton's law of motion, which says that an object in motion does not change its motion unless it is pushed or pulled. However note that, as seen by us standing on the Earth, the plane of the pendulum's motion *appears* to rotate—just like the stars appear to rotate around us—making 1 complete turn per day (see Fig. 1). The motion of the Foucault pendulum over the course of the day proves that the Earth is rotating.

The same law of motion predicts something quite different if the Foucault pendulum were located on the Earth's equator, say in Singapore (see Fig. 2). Suppose, for example,

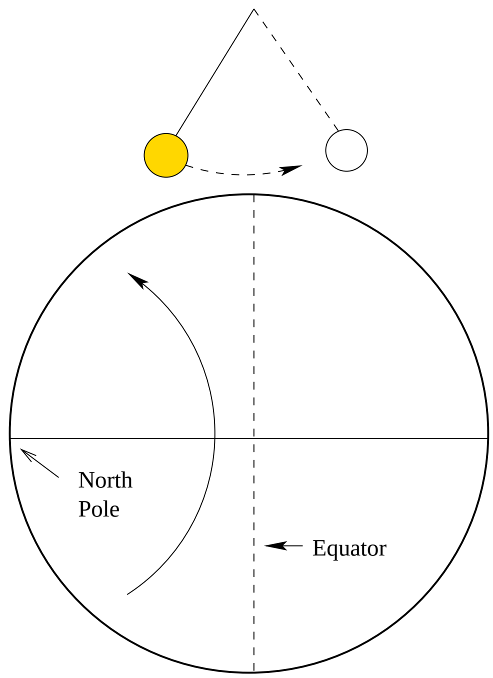

Figure 2: At the equator, the plane of a pendulum's motion would appear not to change.

the pendulum were started moving in a North-South direction. Its motion would be along the line toward Polaris (the north star) and would remain moving in this North-South direction as the Earth rotated. There would be no change in the pendulum's direction of motion with respect to the base; instead the pendulum and the base move together around the Earth's center. A Foucault pendulum on the equator could not demonstrate the Earth's motion (see Fig. 2).

For a Foucault pendulum located at a latitude somewhere in between the North pole and the equator, the situation is intermediate between the two previously described (see Fig. 3). At a given latitude, the relative rotation rate of the earth about the pendulum is given by the component of the Earth's angular momentum vector in that direction,

$$\begin{array}{c}\text{rotation rate for}\\ \text{plane of motion}\end{array} = \sin(\phi) \times 360 \ \frac{\text{degrees}}{\text{day}},$$

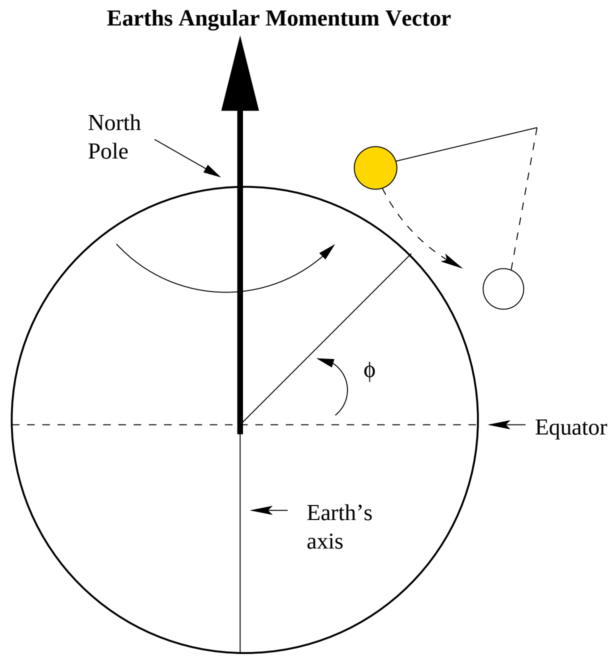

Figure 3: At intermediate latitudes the rotation rate depends on the latitude, ϕ.

where ϕ is the usual measure of latitude, the angle with respect to the equator (see Fig. (3)). This formula agrees with the behavior we deduced previously for the North pole ($\phi = 90$ degrees) and at the equator ($\phi = 0$ degrees). Thus the farther from the equator that the pendulum is located, the faster is its rotation rate.

4 Local Facts

The Foucault pendulum at the Consortium Library is at a latitude of 61 degrees and 11 min. Using the formula derived above, this corresponds to

$$\begin{array}{c}\text{rotation rate at}\\ \text{Consortium Library}\end{array} = 315.4\ \frac{\text{degrees}}{\text{day}},$$

Thus the time it should take for the pendulum to move half-way around the platform, and so be oscillating in the same plane as it was before, is 13.7 hours.

The length of a pendulum determines its oscillation period. For the Foucault pendulum at the Consortium Library, the pendulum is 11.5 meters long which corresponds to an oscillation period of 6.80 seconds. The pendulum bob is made of cast brass and weighs 235 pounds [5]. The bob is supported by a 1/8 inch galvanized steel cable. At the top of the cable is a delicate support system with a small electromagnet that adds energy to the system—to balance the energy lost due to air resistance. The amplitude of the oscillations is thus somewhat adjustable, with a typical value being about 4 degrees from vertical.

5 Suggested Activities

1. On a piece of paper (see next page), make a sketch showing the pendulum's path at the present time. Predict what this path will look like a couple of hours from now, then come back later and see if your prediction is correct. Did you get the direction of change correct? Did you get the size of the change correct? Does the equation given above accurately describe what the pendulum is doing?

2. Measure the period, T, of the pendulum's motion. Using the equation $T = 2\pi\sqrt{L/g}$, where L is the length of the pendulum and g is the acceleration of gravity ($g = 9.8m/s^2$), calculate the length of the pendulum [6]. Does this match the length that you observe directly? Test this equation at home using pendulums that you make yourself.

3. Put a pendulum on a platform that can be rotated. Start the pendulum moving, and observe what happens as you rotate the platform. (This would make a good science project).

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References

[1] In 1992 the Vatican admitted that errors were made in the case of Galileo but never admitted that it was wrong to find him guilty. See www-groups.dcs.st-and.ac.uk/ history/Mathematicians/Galileo.html

[2] W. Tobin, 'Leon Foucault', Scientific American 279, 52-59 (July 1998).

[3] C. J. Cunningham, 'How Do We Know Earth Rotates?', Mercury Magazine, (July-Aug 2002) p. 13. Reproduced at http://www.lawrencehallofscience.org /gems/rotates.html

[4] Amir D. Aczel,'Pendulum : Leon Foucault and the Triumph of Science', Atria Books, New York (2003).

[5] California Academy of Sciences, http://www.calacademy.org/products/pendulum.html

[6] This equation is derived in most introductory physics text books.

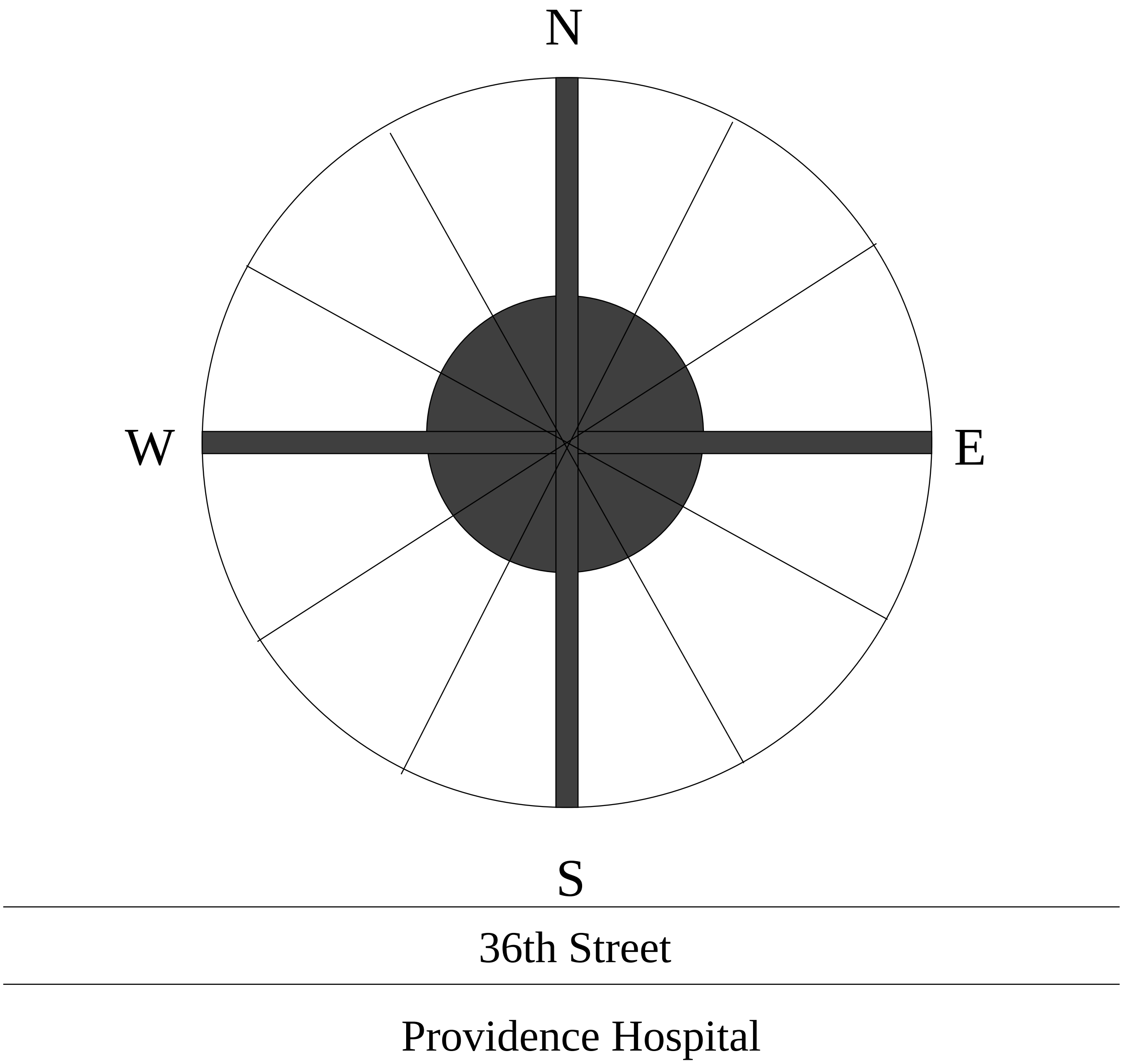

Figure 4: Sketch where the pendulum is now and where it will be when you come back later.