Foucault's Pendulum

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Abstract

Science students always feel curious to learn and also visualize the revolution of earth around its own axis in 24hrs. The introduction of the Foucault pendulum in 1851 somehow overcame all the bottlenecks and aligned itself with the Rest of the Universe and was the first dynamical proof of the rotation of earth in an easy-to-see experiment and it created a justified sensation in both the learned and everyday worlds. Today, Foucault pendulums are popular displays in science museums and universities world over. This article, briefly presents the topics like history, mechanics, construction and setting up about Foucault's pendulum with a hope that it will act as a source for its readers to understand the physics of Foucault's pendulum in a simple manner.

1. Introduction

People already knew, at the time, that the Earth turned around its own axis in 24hrs and also goes around the Sun, once every year. The Sun, in turn, goes around the centre of our galaxy, The Milky Way, once every 250 million years. These are all local motions. The cycle of night and day was already very convincing proof of earth's rotation about its own axis but the French physicist Léon Foucault wanted to prove it without resorting to any celestial elements that had already been done 218 years earlier by Galileo. The introduction of the Foucault pendulum in 1851 somehow ignores all these local motions and somehow aligns itself with the Rest of the Universe and was the first dynamical proof of the rotation of earth in an easy-to-see experiment and it created a justified sensation in both the learned and everyday worlds. Today, Foucault pendulums are popular displays in science museums and universities world over and author has the opportunity to see the Foucault pendulum installed at Physical Research Laboratory (PRL) Ahmadabad (Gujarat). Its action is a result of the Coriolis effect. It is a tall pendulum free to oscillate in any vertical plane and ideally should include some sort of motor so that it can run continuously rather than have its motion damped by air resistance.

Main installation

Pendulum bob

2. History

Mr. Foucault—a surgeon by training, physicist, inventor and journalist by trade—was not looking for direct proof that the planet rotates. The Foucault pendulum was invented by accident. In 1848 Leon Foucault was setting up a long, skinny metal rod in his lathe. He "twanged" it, and the end of the piece of metal proceeded to go up-and-down. If you treat the chuck of the lathe like a clock, the end vibrated from 12 o'clock down to 6 o'clock, and back to 12 o'clock, and so on. He slowly rotated the chuck by 90 degrees. But the end of the metal rod steadfastly vibrated back-and-forth between 12 and 6 o'clock! This set Leon Foucault thinking. He set up a small pendulum in his drill press. He set the pendulum oscillating, and then started the drill press. Once again, the pendulum kept swinging in its original plane, and ignored the fact that its mounting point was rotating. He then constructed a 2 metre-long pendulum with a 5 kilogram ball in his workshop in his cellar. Before the amplitude of the swing died away totally, he saw that the weight on the end of the pendulum appeared to rotate clockwise .

Now that he was convinced of the principle, he built a second pendulum with an 11-metre wire in the Paris Observatory, and it too rotated clockwise. He was asked to construct something "big" for the 1850 Paris Exhibition, and he constructed a 67-metre tall Foucault pendulum in the PanthŽon - a Parisian church also known as the church of Saint Genevi ve. He went to a great deal of trouble to make sure that the wire was perfectly symmetrical in its metallurgy. He used a 28 kilogram cannon ball. A stylus was placed under the ball, and sand was scattered under the potential path of the ball, so that the stylus would cut a trace in the sand. The ball was pulled to one side, and held in place with a string. With much ceremony, the string was set alight, and the ball began to describe a beautiful, straight (non-elliptical) path in the sand. Within a few minutes, the pendulum had begun to swing a little clockwise - and the previous, narrow straight-line in the sand had widened to look like a twin-bladed propeller. The experiment was a success. The Earth rotated "under" his pendulum. So it was possible, way back in 1850, to set up an experiment inside a room which had no view of the outside world, and prove that the Earth rotated. The next year, Foucault repeated his Pendulum experiment with a massive, spinning weight. He showed that this weight, just like his Pendulum, ignored local effects and lined itself up with the distant stars.

During Foucault's life it was already proven that the Earth rotated; thanks to experiments which showed that weights dropped from tall towers fell slightly to one side rather than straight down. This is the Coriolis Effect in action. Essentially, the weight does fall in a straight line towards the centre of the Earth, as you would expect, but the Earth rotates slightly during its fall. It is the tower and the ground which move sideways, not the weight. Incidentally, pilots on long flights have to correct for this effect; if they took off, pointed their plane at a distant destination and maintained a straight course, their arrival airport would no longer be there when they arrived.

The first public exhibition of a Foucault pendulum took place in February 1851 in the Meridian of the Paris Observatory. A few weeks later Foucault made his most famous pendulum when he suspended a 28 kg brass-coated lead bob with a 67 meter long wire from the dome of the Panthéon, Paris. The plane of the pendulum's swing rotated clockwise 11° per hour, making a full circle in 32.7 hours. The original bob used in 1851 at the Panthéon was moved in 1855 to the Conservatoire des Arts et Métiers in Paris. A second temporary installation was made for the 50th anniversary in 1902. During museum reconstruction in the 1990s the original pendulum was temporarily displayed at the Panthéon (1995), but was later returned to the Musée des Arts et Métiers before it reopened in 2000. On April 6, 2010 the cable suspending the bob in the Musée des Arts et Métiers snapped, causing irreparable damage to the pendulum and to the marble flooring of the museum. An exact copy of the original pendulum has been swinging permanently since 1995 under the dome of the Panthéon, Paris.

3. Explanation of mechanics

Newton's law of motion states that when a body is set in motion, it will move in a straight line from its origin, as long as it is not influenced by outside forces. This was the concept upon which Foucault based his proof that the earth rotates. If you start a Foucault pendulum swinging in one direction, after a few hours you will notice that it is swinging in a quite different direction. The earth, on the other hand, will rotate once every 24 hours underneath the pendulum. Thus if you stood watching the pendulum, after a quarter of an hour or so, you would be likely to notice that the line of the pendulum's swing has changed to a different direction. This would be especially clear if one marked the position of the line of swing in the morning and had the pendulum knocking down pegs arranged in a ring at the center. However, if you are standing on the floor of a building housing a pendulum (which is connected to the earth), you will naturally think that the floor is stable and the pendulum is moving. This is because we naturally assume that the base on which we stand is stable unless our eyes or sense of balance tells us otherwise. If our base moves slowly or accelerates smoothly, we are easily fooled into thinking that another object we see is moving. Thus, after thinking for a while about the total situation you might be willing to agree that what you are seeing is a real demonstration that the earth is rotating under the pendulum and that the line of swing of the pendulum just appears to rotate.

The Earth's rotation causes the trajectory of the pendulum to change over time, knocking down pins at different positions (or oscillating in different marked directions in a circle) as time elapses and the Earth rotates. The experimental apparatus consists of a tall pendulum free to swing in any vertical plane. The actual plane of swing appears to rotate relative to the Earth. The wire needs to be as long as possible—lengths of 12–30 m (40–100 ft) are common. At either the North Pole or South Pole, the plane of oscillation of a pendulum remains fixed relative to the distant masses of the universe while Earth rotates underneath it, taking one sidereal day to complete a rotation. A pendulum day is the time needed for the plane of a freely suspended Foucault pendulum to complete an apparent rotation about the local vertical. This is one sidereal day divided by the sine of the latitude. So, relative to Earth, the plane of oscillation of a pendulum at the North Pole undergoes a full clockwise rotation during one day; a pendulum at the South Pole rotates counterclockwise. When a Foucault pendulum is suspended at the equator, the plane of oscillation remains fixed relative to Earth. At other latitudes, the plane of oscillation precesses relative to Earth, but slower than at the pole; the angular speed, ω(measured in clockwise degrees per sidereal day), is proportional to the sine of the latitude, φ ($\omega = 360 \sin\varphi$ °/day), where latitudes north and south of the equator are defined as positive and negative, respectively.

4. Construction and setting up

The Foucault pendulum (support + wire + iron ball) is attached to this building. Any pendulum consists of a cable or wire or string and a bob. For a pendulum to easily demonstrate the Foucault effect, it should have as long a cable as possible (this one is 52 feet) and a heavy symmetrical bob (this one is hollow brass, weighing about 240 pounds). Like all pendulums this one loses a bit of energy with each swing due to friction from air currents and vibrations in the cable and other factors. Thus, left to itself the pendulum would swing in shorter and shorter arcs until after a few hours it will decrease almost to zero. To keep the Foucault pendulum going, one must replace the energy lost with each swing. This can be done by giving the pendulum a little "kick" with each swing. To do this, two iron collars are attached to the cable near the top. There is a doughnut-shaped electromagnet built into the ceiling, and the iron collar swings back and forth inside the hole of the doughnut. When the pendulum cable reaches a particular point in its swing, it is detected by an electronic device and the magnet is turned on at just the right time to give the collar (and thus the cable and the bob) a little "kick" in the exact direction of its natural swing. This restores the energy lost during the swing and keeps the pendulum from stopping. It has no effect on the direction of the swing, and thus does not interfere with the demonstration that the earth is rotating.

At either the North Pole or South Pole, the plane of oscillation of a pendulum remains pointing in the same direction while the Earth rotates underneath it, taking one sidereal day to complete a rotation. When a Foucault pendulum is suspended somewhere on the equator, then the plane of oscillation of the Foucault pendulum is at all times co-rotating with the rotation of the Earth. What happens at other latitudes is a combination of these two effects. At the equator the equilibrium position of the pendulum is in a direction that is perpendicular to the Earth's axis of rotation. Because of that, the plane of oscillation is co-rotating with the Earth. Away from the equator the co-rotating with the Earth is diminished. Between the poles and the equator the plane of oscillation is rotating both with respect to the stars and with respect to the Earth. The direction of the plane of oscillation of a pendulum with respect to the Earth rotates with an angular speed proportional to the sine of its latitude; thus one at 45° rotates once every 1.4 days and one at 30° every 2 days.

A Foucault pendulum is tricky to set up because imprecise construction can cause additional veering which masks the terrestrial effect. Air resistance damps the oscillation, so Foucault pendulums in museums usually incorporate an electromagnetic or other drive to keep the bob swinging. Its oscillations continue with reassuring regularity, its movement maintained by an electromagnetic device in the base of the installation. Once a pendulum has been set in motion, it does not change the direction in which it swings. The pendulum is only attached to the Earth at a single point, which allows it to maintain its direction of oscillation. Another phenomenon, then, must be responsible for the progressive fall of the pins. Indeed, it is not the pendulum that turns, but the Earth, turning beneath the pendulum. The rotation of the instrument is only apparent; it is us, the building, the table and little pins, all firmly attached to the Earth, that are turning around the pendulum.

5. Precautions

A Foucault pendulum requires care to set up because imprecise construction can cause additional veering which masks the terrestrial effect. The initial launch of the pendulum is critical; the traditional way to do this is to use a flame to burn through a thread which temporarily holds the bob in its starting position, thus avoiding unwanted sideways motion. Air resistance damps the oscillation, so some Foucault pendulums in museums incorporate an electromagnetic or other drive to keep the bob swinging; others are restarted regularly, sometimes with a launching ceremony as an added attraction.

6. Conclusion

We all know that the Earth rotates, even if we rarely contemplate the fact, but watching a Foucault pendulum is a humbling reminder that we're all on the surface of a planet spinning in space. That intuitive impact is exactly why this experiment remains so famous. Mechanically, it's one of the simplest experiments possible: a heavy weight attached to a very long string or cable that is free to swing in any vertical plane. This pendulum is set in motion very carefully to avoid introducing any sideways motion, usually by tying it back with a thread of cotton which is then burned with a candle. Oddly, it will then appear to change its direction of swing over time without any outside input. Of course, it is actually the Earth which is rotating, while the pendulum continues to swing in the same plane relative to the rest of the Universe. The Foucault pendulum is currently working. The main problems involved in making a Foucault Pendulum are starting the ball in a swing that passes through the true centre point of the swing, keeping the ball in that "true" swing (and not going into an elliptical swing), and pumping energy into the swing so that it does not die down. Three subsystems were set up to achieve these goals, and currently, they are all operational.

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