Foucault Pendulum KSCIFCPN

INTRODUCTION

Jean Bernard Léon Foucault's famous 1851 experiment with a long pendulum in the Panthéon in Paris used a 27 kg pendulum bob suspended on a 67m wire, and demonstrated that the pendulum's plane of swing precessed with the rotation of the Earth. This was the first direct dynamic evidence that the Earth rotates about a polar axis, and the phenomenon has been a popular topic of discussion ever since.

The precession of Foucault's pendulum is often poorly explained. At the Earth's poles, the plane of the swing remains constant relative to the fixed stars and appears to an Earth-based observer to rotate once every sidereal day. At the equator, the plane of swing co-rotates with the Earth and the pendulum does not appear to precess at all. At other latitudes, the behavior is intermediate between these extremes and the pendulum precesses with respect to both the Earth and the fixed stars. At 30° latitude, the apparent precession takes two days. If the motion is analyzed using a co-rotating coordinate system, then the force causing the precession is just the Coriolis force experienced by the moving bob.

This Foucault's Pendulum Apparatus is a carefully constructed miniature version of Foucault's device. Since the forces causing the precession are small, the effect is easily disturbed by other small environmental forces. To eliminate drafts, the pendulum is enclosed in a glass case, and the heavy vibration-damping base is equipped with leveling feet. The pendulum is electrically maintained to counter air resistance damping, and the swing amplitude can be adjusted using a potentiometer.

The suspension device ensures accurate centering of the pendulum's rest position over a graduated circle below the bob. The graduated circle carries an adjustable double-ended indicator bar for precise measurement of the plane of swing when tracking the precession rate.

The durable steel case is attractively finished suitable for permanent display, with a plaque carrying a brief description of Foucault's experiment.

SPECIFICATIONS AND DESCRIPTION

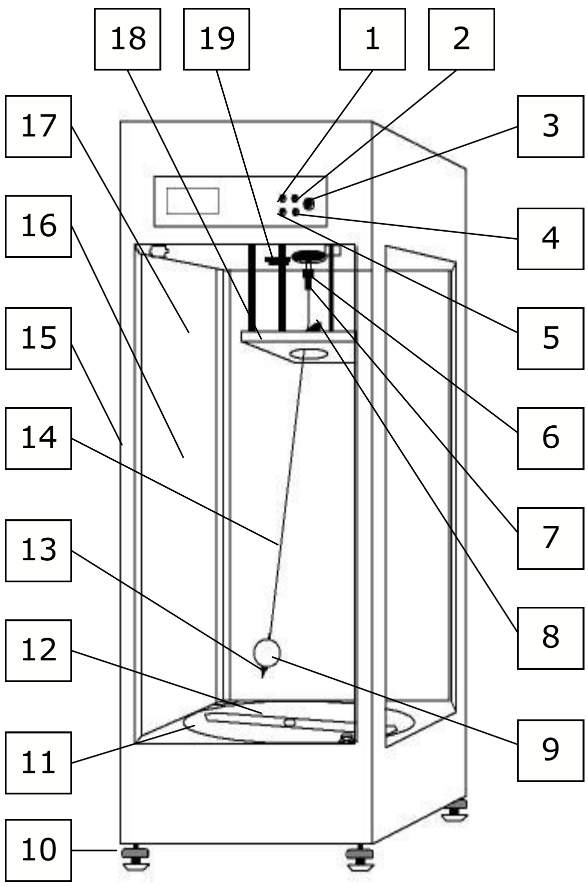

Figure 1

Refer to *Figure 1 above*

1. Power indicator lamp
2. Maintenance voltage indicator lamp
3. Amplitude adjustment knob
4. Illuminating lamp switch
5. Power switch
6. Pendulum support
7. Pendulum wire attachment clamp
8. Centering device
9. Pendulum bob
10. Leveling foot (one of four)
11. 360° graduated disk
12. Double-ended indicator bar
13. Pointer
14. Pendulum wire (0.3mm diameter steel)
15. Case frame
16. Glass side panel
17. Glass door
18. Centering device plate with centering ring
19. Illuminating lamp

SPECIFICATIONS

Pendulum length:	975mm	Mass of bob:	approx.1kg
Period:	approx. 1.9s	Period tolerance:	≤± 10%
Power:	110VAC ± 10%, 50-60Hz		
Environment:	0—40°C, ≤ 85% RH		
Dimensions:	40 cm x 40 cm x 140 cm	Weight:	approx. 50 kg

DESCRIPTION

The instrument is mounted in a steel cabinet with glass windows on three sides and a glass door at the front for protection against drafts. The door allows access to the pendulum and indicator bar for adjustment. The pendulum support and centering mechanism, and also the electrical equipment for illuminating the pendulum and controlling its motion, are mounted in the upper part of the cabinet, with the controls arranged on a front panel (see *Figure 2*.) Four adjustment feet allow the instrument to be set up vertically using a bubble level mounted on the base.

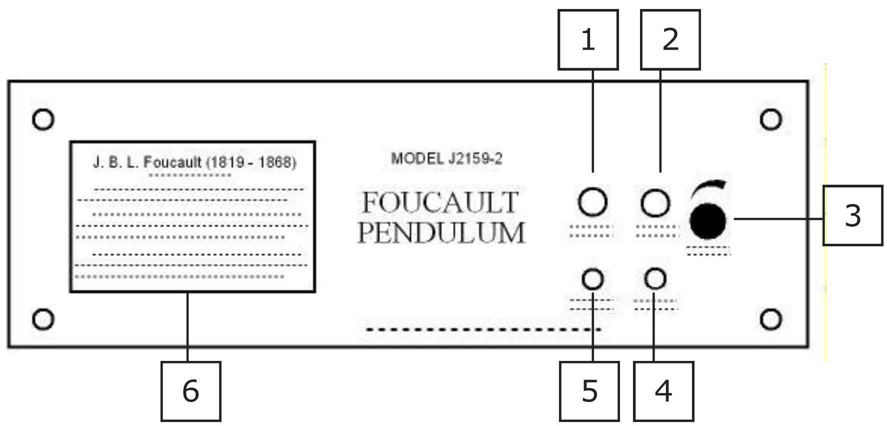

Figure 2

1. Power indicator lamp
2. Maintenance voltage indicator lamp
3. Amplitude adjustment knob
4. Illuminating lamp switch
5. Power switch
6. Plaque with Foucault background data

The pendulum consists of a length of 0.3 mm diameter steel wire carrying a spherical cast iron bob. The upper end of the wire is attached to a central clamp mounted in the base of the upper cabinet section. The wire then passes through a limiting ring in the center of a horizontal plate that carries a calibration screw and feeler used to ensure that the wire passes through the exact center of the ring. The lower end of the bob carries a pointer. The base of the cabinet is fitted with a circular disk graduated 360° for reading the plane of the pendulum swing. An indicator bar mounted at the center of the disk can be rotated by hand to mark the starting angle of the plane of swing. The lower section of the cabinet also contains the electromagnet used to maintain the pendulum's swing amplitude.

OPERATING PRINCIPLE

As mentioned in the introduction, the swinging pendulum experiences a Coriolis force due to the rotation of the earth. This rotation causes the suspension of the pendulum to move in a circle relative to a fixed point in space. The diameter of the circle and the angle its axis makes with pendulum's local vertical direction both depend on the geographic latitude of the pendulum. This angle is the determining factor in the pendulum's precession, since the perceived Coriolis force acts at right angles to both the direction of motion of the bob and the axis of the rotation.

At the equator, the only direction which is at right angles to both of these quantities is along the pendulum wire (as long as the amplitude of the oscillation is small,) so the only effect of the Coriolis force is to make the bob appear slightly heavier or lighter. This has a very small effect on the pendulum's period, but does not cause any precession of the plane of the swing.

At either pole, every direction of swing is at right angles to the axis of rotation, so the Coriolis force is always in a direction at right angles to the plane of the swing and the effect is a maximum.

For other latitudes, the effect of the Coriolis force is progressively less as the latitude decreases, and the pendulum will take a correspondingly longer time to precess by one complete revolution.

An exact analysis is best done using co-rotating coordinates, and is complex*. However, the resulting expression for the rate of precession is comparatively simple:

$$\omega = \Omega \sin\phi$$

where ω is the angular rate of the pendulum's precession, Ω is the earth's angular velocity, and ϕ is the latitude of the pendulum's location. ϕ is positive for the northern hemisphere and negative for the southern hemisphere. So the pendulum precesses clockwise for northern locations and counterclockwise for southern ones.

At the poles, $\sin\phi = 1$ or -1 respectively, so the pendulum precesses one complete revolution in one sidereal day.

The value of Ω is 7.292×10^{-5} radians/sec, which is more usefully expressed as 15.04°/hour, so the precession rate of the pendulum becomes:

$$15.04\sin\phi \text{ °/ hour.}$$

Some examples of precession rates and the time needed for one complete revolution for several cities are given in *Table 1*.

City	Latitude	Rate (°/hr.)	Time/rev. (hr.)	City	Latitude	Rate (°/hr.)	Time/rev. (hr.)
Chicago	41° 52′ N	10.04	35.85	Caracas, Venezuela	10° 29′ N	2.74	131.39
Dallas	32° 46′ N	8.14	44.23	London, England	51° 30′ N	11.77	30.58
Miami	25° 46′ N	6.54	55.04	Moscow, Russia	55° 45′ N	12.43	28.96
New York	40° 43′ N	9.81	36.70	Rome, Italy	41° 54′ N	10.04	35.85
San Francisco	37° 48′ N	9.22	39.04	Shanghai, China	31° 14′ N	7.80	46.10
Washington, D.C.	38° 53′ N	9.44	38.14	Sydney, Australia	33° 51′ S	-8.38	42.96

Table 1—Precession rates for various locations

* For those wishing to explore further, there are a number of good websites with analysis at varying degrees of difficulty. Wikipedia offers many links from www.wikipedia.org/wiki/Foucault_Pendulum.
See also www.sciencebits.com/foucault for a rotating coordinates analysis.

The Coriolis Effect is small due to the small angular velocity of the earth, and is not readily detected in a laboratory experiment. The Foucault pendulum offers the simplest means of demonstrating the effect. From the times shown in the table, it is clear that the pendulum must be maintained in motion for a considerable time in order to make reasonably accurate measurements. For short, light pendulums, air resistance quickly damps the motion. Foucault's original experiment relied on an extremely long and heavy pendulum to minimize air resistance, but this is impractical in the laboratory, so the current design uses a moderate length and weight as well as an electromagnet with timed pulses and draft shielding to maintain the motion and swing plane free of disturbance.

INSTALLATION

ASSEMBLING THE GLASSWARE

For shipping safety, the three glass side and rear panels and the glass door are packed separately from the metal cabinet and the pendulum.

1. Install the 3 mm thick side and rear glass panels into their frames.
   The glass panels are held in place in their frames by metal retaining strips mounted on the inner edges of the frames. Loosen the retaining strips and carefully insert each panel into its frame. Fit the 1 mm thick rubber gaskets between the glass and the retaining strips before tightening the strips in place. **TAKE CARE NOT TO OVER-TIGHTEN THE RETAINING STRIPS TO AVOID CRACKING THE GLASS**.
2. Install the 5 mm thick glass door.
   First insert the 5 mm diameter pins of the two metal hinge plates into their respective holes in the cabinet, top and bottom on the right side of the door opening. The two metal washers are fitted onto the lower hinge plate before insertion (see *Figure 3.*)

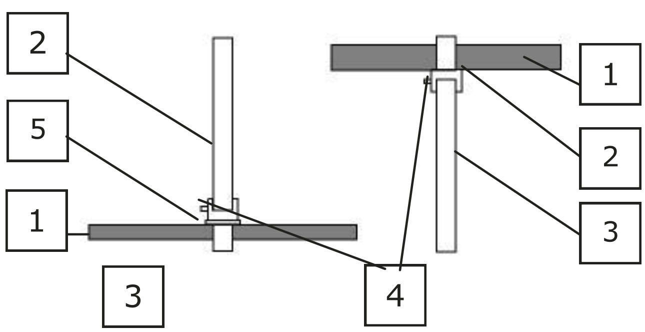

Figure 3
1—Door frame, 2—Hinge plate, 3—Glass door, 4—Screws, 5—Washers

   Align the channels of the hinge plates parallel to one another and carefully slide the glass door into place. Tighten the screws on the hinges plates to hold the door in place. **TAKE CARE NOT TO OVERTIGHTEN THE SCREWS TO AVOID CRACKING THE GLASS.** Check that the door swings freely and is correctly oriented in its opening. Fit the U-shaped steel catch plate over the top left edge of the door and attach the magnetic catch to the door frame.

SETTING UP THE INSTRUMENT

1. Site the instrument.
   Choose a location for the instrument that has a stable, level surface, preferably away from a high traffic area. Place the instrument where it will not be necessary to move it or change its orientation after adjustment.

2. Attach the bob
   Thread the 4 mm long piece of plastic tubing over the end of the pendulum support wire. Insert the covered end of the wire into the pendulum bob clamp until the end of the wire projects 2-3 mm from the bottom of the clamp. Adjust the position of the plastic tubing in the clamp so that its upper end is flush with the top of the clamp. Tighten the clamp onto the bob. Check the position of the pointer below the bob. With the bob at rest over the center of the graduated disk, the end of the pointer should be 1-2 mm above the disk.

3. Level the instrument and center the suspension.
   Using the four leveling feet, adjust the unit until the base is horizontal. The pointer on the bob should then be centered on the hole in the middle of the graduated disk. Use the screw of the centering device on the suspension to check that the support wire passes exactly centrally through the limiting ring. This is factory adjusted, but it should be checked during setup and adjusted if necessary. The adjustment procedure is as follows:

   - Loosen the four screws supporting the centering device plate
   - Adjust the centering device screw until its tip just touches the pendulum wire in its rest position
   - Rotate the centering device plate 90° and check that the screw tip still touches the wire (see *Figure 4*.) Adjust the plate position if necessary.

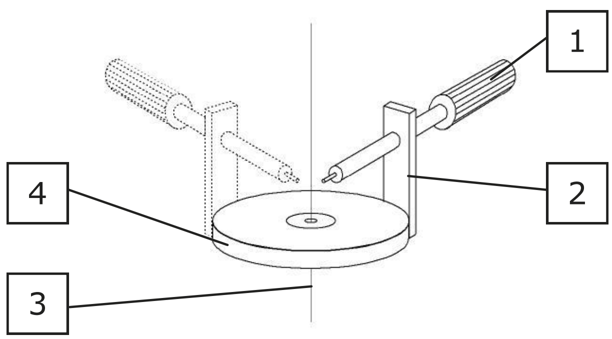

Figure 4
1—Screw, 2—Support frame, 3—Pendulum wire, 4—Plate

   - Repeat the adjustment of the centering device plate position until the tip of the centering screw just touches the wire in both positions. Tighten the screws of the plate and retract the centering screw so that it does not interfere with the pendulum swing in operation.

OPERATION

INITIAL OPERATION

1. Connect the power cord to a 110VAC outlet and turn on the power switch. The power indicator lights up.
2. Open the door and gently pull the pendulum ball aside until the wire just touches the rim of the limiting ring. The maintenance voltage indicator will light.
3. Hold the bob with the thumb and forefinger and orient your hand so that on release the pendulum will swing directly towards the center of the graduated disk. Release the bob, trying to give the pendulum as little sideways motion as possible.

4. Allow 15 minutes for the pendulum to settle into a regular linear motion. If the amplitude of the swing is too large or too small, use the amplitude adjustment knob to correct it. When properly adjusted, the maintenance voltage lamp should light briefly every half-swing and the peak of each swing should have the pointer on the bob lie approximately over the numerals on the graduated disk.

MEASUREMENTS

1. When the pendulum has settled down to regular motion, align the index marks on the indicator bar with the line of sing of the pendulum and gently close the door.
2. Note the angle reading of the indicator bar and the time.
3. After about 6 hours, note the angle reading of the pendulum's plane of swing and the time. Calculate and record the elapsed time and the angle through which the plane of swing has processed. The built-in illumination lamp may be used to aid reading the graduated disk.
4. Compare the measured result to the theoretical value for the latitude of your location, and calculate the relative error of your measurement. Sample results for the location of manufacture (Tientsin, China, latitude 39.1°N) are given in *Table 2*.

Theoretical precession rate = 15.04 x sin(39.1) °/hr. = 9.48 °/hr.

Time				Elapsed Time (hr)	Precession angle (°)		Relative Error (%)
Start		End			Theoretical	Measured	
March 10	9:30 a.m.	March 10	3:30 p.m.	6.0	56.91	55.29	2.85
March 10	9:30 a.m	March 10	9:30 p.m.	12.0	113.82	110.74	2.71
March 10	9:30 a.m	March 11	3:30 a.m	18.0	170.73	166.76	2.33
March 10	9:30 a.m	March 11	9:30 a.m	24.0	227.64	221.18	2.84

Table 2—Sample results for Tientsin, China

MAINTENANCE

1. Choose a location which is stable and level, free from vibration, drafts, strong magnetic fields and moisture, and where a conveniently placed electrical outlet is available that can remain switched on continuously.
2. For correct operation, it is important that the instrument is properly leveled and that the pendulum wire is accurately centered in the limiting ring—see the setup instructions above for details of the procedure.
3. Should you need to replace the pendulum wire, use a high strength 0.3 mm diameter steel wire. The wire should be smooth with no rust or kinks
4. The illumination lamp uses a 110V/40W incandescent bulb.
5. If the observed precession rates show an unusually large error, check the following:
    - Check if there is oil, dust, or rust on the pendulum wire or the limiting ring lip and clean if necessary to maintain good electrical contact
    - Check that the amplitude of the swings is not too large and adjust if necessary with the amplitude control knob. The pendulum should only touch the limiting ring briefly at each half-swing.

- Check that the pendulum wire is properly centered in the upper and lower clamps.
- Check that the instrument is properly leveled and that the wire hangs exactly centrally in the limiting ring—see above for details
- Check that the angle readings are not erroneous due to parallax error in reading the graduations—choose the observing position to eliminate this.

6. If the power indicator lamp and the illuminating lamp will not light, check the fuse. DISCONNECT THE UNIT FROM THE ELECTRICAL OUTLET BEFORE REMOVING THE FUSE. The fuse rating is 250V/0.5A.

7. A schematic of the layout of the electrical circuit is given in *Figure 5* for troubleshooting.

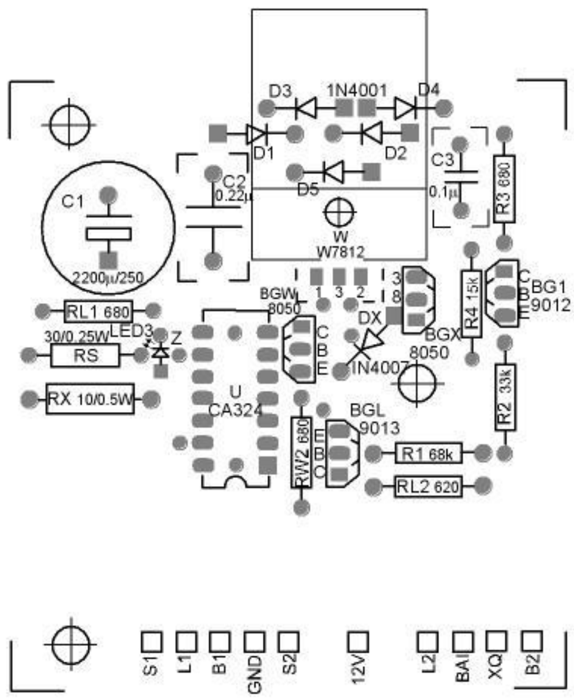

Figure 5

KLINGER SCIENTIFIC Bringing You Science Since 1955