

## Armillary Sundial

An armillary sundial is essentially an armillary sphere set to a fixed orientation based on the sundial's location.

An armillary sphere consists of a set of interlocking metal rings that form a spherical framework around a fixed rod, which represents the polar axis of the sky as seen from earth. A small model of the earth is sometimes attached to the rod's center inside the sphere. The metal rings, usually made of brass or bronze, are referred to as *armilla*, which is Latin for *bracelet*. Armilla were prestigious armbands awarded to Roman soldiers for distinguished gallantry.

Unlike a celestial globe, which has a solid surface upon which the stars are illustrated, the armillary sphere is an open skeletal frame that lacks any depictions of the stars and constellations, except perhaps for its zodiacal ring. It is interesting to note that the image of an armillary sphere is sewn on the Portuguese flag, while that of a celestial globe is represented on the flag of Brazil, once a colony of Portugal.

Armillary spheres existed in Greece and China as early as the 4<sup>th</sup> Century BC. Mechanical versions were later introduced with moveable horizon rings and other features such as a positionable sun. As one of the first planetarium devices, the mechanical armillary sphere was used both for astronomical observations and teaching purposes.

An armillary sphere is ideally suited as a sundial. With its hour face inscribed on the inner circular surface of the *Equatorial* ring—also known as the *Equinoctial*—the gnomon's shadow sweeps uniformly along with time, allowing the hour markings to be equally spaced along the equinoctial ring.

An armillary sphere can be turned into an armillary sundial by setting its celestial polar axis equal to the latitude of the sundial's location and directed at the North Celestial Pole. The sphere's *Horizon* ring is fixed parallel to the terrestrial horizon. And finally the meridional ring called the *Solstitial Colure*, which passes through the celestial poles and the two solstices, is rotated to the vertical position so as to coincide with the local meridian of the sundial's location.

The nomenclature of an armillary sphere is based on the terminology of the following astronomical coordinate systems (see table).

<b>Armillary Sphere</b>	<b>Celestial Coordinate System</b>	<b>Geographical Coordinate System</b>	<b>Horizon Coordinate System</b>
gnomon	celestial polar axis	terrestrial polar axis	terrestrial polar axis
North Celestial Pole	North Celestial Pole	North Geographic Pole	North Celestial Pole
South Celestial Pole	South Celestial Pole	South Geographic Pole	South Celestial Pole
Equinoctial	Celestial Equator	Equator	
Equinoctial Colure			
Solstitial Colure			local meridian (upper half) + antimeridian (lower half)
Tropic of Cancer	Tropic of Cancer	Tropic of Cancer	
Tropic of Capricorn	Tropic of Capricorn	Tropic of Capricorn	
Arctic Circle	Arctic Circle	Arctic Circle	
Antarctic Circle	Antarctic Circle	Antarctic Circle	
Prime Vertical			
Ecliptic (Zodiac)	Ecliptic (Zodiac)		
Horizon			horizon
Zenith			zenith
Nadir			nadir
center of earth	center of earth	center of earth	observer

### Terminology of astronomical coordinate systems

**Colure** is one of two principal meridians (great circles) on the celestial sphere—equinoctial colure and solstitial colure.

- **Equinoctial colure:** meridian or great circle that passes through the celestial poles and the two equinoxes (first point of Aries and first point of Libra).
- **Solstitial colure:** meridian or great circle that passes through the celestial poles and the two solstices (first point of Cancer and first point of Capricorn).

**Local Meridian:** upper half of the great circle that spans from the north horizon to the zenith back down to the south horizon. On an armillary sphere, it forms the upper half of the Solstitial Colure.

**Antimeridian:** lower half of the great circle that spans from the north horizon to the nadir back up to the south horizon. On an armillary sphere, it forms the lower half of the Solstitial Colure.

**Equinoctial:** refers to the celestial equator. The term equinoctial refers to the fact that the vernal and autumnal equinoxes occur when the sun passes through this great circle. The celestial equator is a projector of the earth's equator onto the celestial sphere. The hour markings of the armillary sundial are inscribed on the inner surface of this ring.

**Horizon:** in astronomy, the unobstructed horizon is the circumference of the plane tangent to the earth's surface at the observer's location that intersects the celestial sphere. The horizon's altitude is  $0^\circ$ .

**Zenith:** the overhead position on the celestial sphere as reckon in the horizon coordinate system. The zenith's altitude is  $90^\circ$ .

**Nadir:** the position on the celestial sphere as reckon in the horizon coordinate system is diametrical opposite the zenith. The nadir's altitude is  $-90^\circ$ .

**Prime Vertical:** the great circle that passes through the zenith and nadir, and intersects the horizon at its east and west points.

**Ecliptic:** apparent path of sun on the celestial sphere. The ecliptic is the great circle formed by the intersection of the earth's orbit projected onto the celestial sphere.

**Zodiac:** band  $18^\circ$  wide that is centered on the ecliptic.

**Obliquity:** Earth's axial tilt or obliquity of the ecliptic is defined as the angle that its rotational axis makes with its orbital plane (ecliptic). The earth's axial tilt is currently  $23^\circ 26.2'$  or  $23.44^\circ$ . Since the earth's orbital plane is affected by the other planets in the solar system, its axial tilt varies over time. Data over the past 5 million years show that the obliquity varies from  $22.1^\circ$  and  $24.5^\circ$  over about 41,000 years. Currently the earth's obliquity is slowly decreasing towards the low values. There are other shorter-term variations in the obliquity, such as nutation, which is caused by the moon and varies over 18.6 years.

**Tropic of Cancer:** This small circle (also called the Northern Tropic) forms the northernmost latitude on earth at which the noontime sun can cross the zenith. This occurs around June 21 — and is called the summer solstice in the northern hemisphere. A corresponding circle, also called the Tropic of Cancer, is formed by the projection of the earth's Tropic of Cancer onto the celestial sphere. In ancient times, the sun passed through the zodiacal constellation of Cancer at this time of year — thus its name Cancer. The word "tropic" derives from the Greek word meaning *turn* — referring to the point on the sky where the sun changes direction and begins moving south as winter approaches in the

northern hemisphere. Today, while precession (the wobble of the earth on its axis) has shifted the summer solstice into the constellational of Taurus, the solstitial sun remains in the astrological sign of Cancer, which is unaffected by precession. The Tropic of Cancer is currently at latitude  $23^{\circ} 26.2' N$  or  $23.44^{\circ} N$ . Like the obliquity, the latitude of the Tropic of Cancer varies from  $22.1^{\circ} N$  and  $24.5^{\circ} N$  over about 41,000 years. The Tropic of Cancer is moving south toward the equator at about 50 feet per year.

**Tropic of Capricorn:** This small circle (also called the Southern Tropic) forms the southernmost latitude on earth at which the noontime sun can cross the zenith. This occurs around Dec 21 — and is called the winter solstice in the northern hemisphere. A corresponding circle, also called the Tropic of Capricorn, is formed by the projection of the earth's Tropic of Capricorn onto the celestial sphere. In ancient times, the sun passed through the zodiacal constellation of Capricornus at this time of year — thus its name Capricorn. The word “tropic” derives from the Greek word meaning *turn* — referring to the point on the sky where the sun changes direction and begins moving north as summer approaches in the northern hemisphere. Today, while precession (the wobble of the earth on its axis) has shifted the winter solstice into the constellational of Sagittarius, the solstitial sun remains in the astrological sign of Capricorn, which is unaffected by precession. The Tropic of Capricorn is currently at latitude  $23^{\circ} 26.2' S$  or  $23.44^{\circ} S$ . Like the obliquity, the latitude of the Tropic of Capricorn varies from  $22.1^{\circ} S$  and  $24.5^{\circ} S$  over about 41,000 years. The Tropic of Capricorn is moving north toward the equator at about 50 feet per year.

**Arctic Circle:** This small circle forms the northernmost latitude on earth at which the center of the sun's disk travels completely around the horizon for a full 24 hours on the June solstice (summer solstice in the Northern hemisphere). Currently the latitude of the Arctic Circle is  $66^{\circ} 33.8' N$ . The latitude of the Arctic Circle varies from  $67.9^{\circ} N$  and  $65.5^{\circ} N$  over about 41,000 years. The Arctic Circle is moving south toward the equator at about 50 feet per year.

**Antarctic Circle:** This small circle forms the southernmost latitude on earth at which the center of the sun's disk travels completely around the horizon for a full 24 hours on the December solstice (summer solstice in the Southern hemisphere). Currently the latitude of the Antarctic Circle is  $66^{\circ} 33.8' S$ . The latitude of the Antarctic Circle varies from  $67.9^{\circ} S$  and  $65.5^{\circ} S$  over about 41,000 years. The Antarctic Circle is moving north toward the equator at about 50 feet per year.

**Gnomon:** represents the earth's rotational or polar axis. The gnomon inclines to the horizon by an angle equal to the latitude of the observer.

**Meridional:** a great circle running along the meridian—in the north-south direction.

**Great Circle:** a largest circle along the surface of a sphere, whose center coincides with the center of the sphere.

**Small Circle:** a circle along the surface of a sphere, whose center does not coincide with the center of the sphere.