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Earth and Sun – Relationships with our light-giver

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Geometrical basics or why 1+1 equals 23 ½

To simplify the challenges of astronomy and geometry, let us establish a viewing model for our planet and its star. We will consider Earth as a sphere, which appears to an observer at any geographical point as a disk bounded by the horizon. The horizon, in a mathematical sense, is a great circle that divides the celestial sphere into two equal hemispheres, with its pole at the zenith. The natural or landscape horizon, by contrast, is the visible boundary between the sky and Earth, influenced by local topography. Above this horizon rises the celestial sphere, perceived as a hemisphere, with its highest point, the zenith, located 90° from the horizon and directly opposite the nadir (the point directly below the observer).

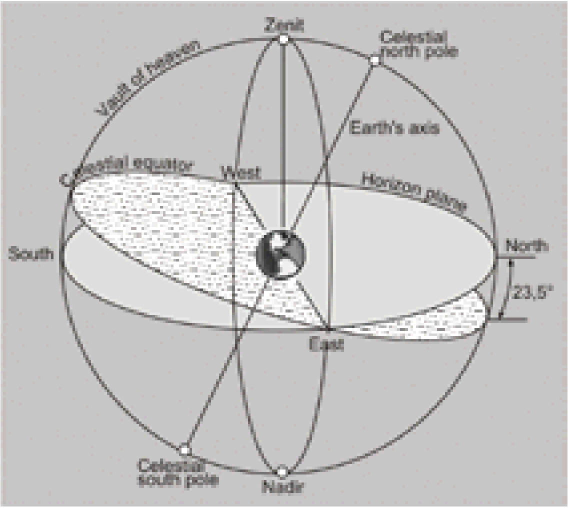

Figure 9: Celestial mechanics

In this simplified horizon system, observed from a distant point in space, we would recognize that Earth orbits the sun counterclockwise along a slightly elliptical path, completing one orbit in approximately 365 days. For simplicity, let us assume, contrary to reality, that Earth's axis is not tilted but perpendicular to its orbital plane around the sun. If we stood together at the equator of this hypothetical Earth with the sun directly overhead and could see the stars alongside the sun, what would we observe? As Earth progresses in its orbit, the sun would appear to shift slightly eastward each day against the background of the fixed stars, returning to its starting position after one year. This apparent path of the sun is called the ecliptic. In this simplified model, with Earth's axis aligned perpendicularly, the ecliptic would coincide with the celestial equator, which is the projection of Earth's equator onto the celestial sphere.

In reality, Earth's axis is tilted by approximately 23.5° relative to its orbital plane, and the key to understanding its effects lies in the fact that this tilt remains nearly constant throughout the orbit. At one point in the orbit, Earth's northern hemisphere is tilted toward the sun, receiving more direct sunlight, while at the opposite point, the southern hemisphere is tilted toward the sun. Returning to our hypothetical observation point at Earth's equator, we can examine the true dynamics.

As Earth progresses in its orbit around the sun, the sun appears to shift slightly eastward each day against the background of fixed stars. Due to the axial tilt, the sun's apparent path, known as the ecliptic, does not follow the celestial equator as it would in a non-tilted model. Instead, it oscillates north and south of the celestial equator over the course of a year. The sun reaches its northernmost point, 23.5° north of the celestial equator, around June 21 (the summer solstice in the northern hemisphere) and its southernmost point, 23.5° south, around December 21 (the winter solstice in the northern hemisphere). At the equinoxes (around March 21 and September 23), the sun crosses the celestial equator, resulting in equal day and night lengths globally. Thus, the ecliptic's path is determined by Earth's orbit around the sun and the tilt of its axis.

The ecliptic is the plane of Earth's orbit around the Sun, or the apparent path of the Sun in our sky as seen from Earth.

This motion can be captured photographically through a multiple-exposure technique, taking images of the sun at regular intervals (e.g., every seven or nine days) at the same time and from the same location over a year. The resulting image displays the analemma, a figure-eight shape reflecting the sun's seasonal north-south motion and its east-west progression. The analemma's horizontal extent is determined by the sun's north-south oscillation, while its tilt depends on the observer's latitude: it appears flat at the equator and vertical at the poles.

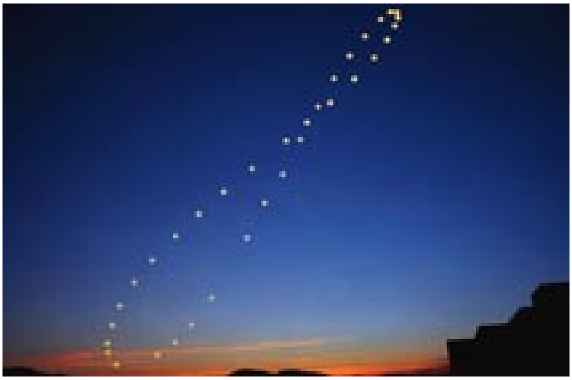

Figure 10: The apparent solar motion Analemma

Thus, we have established the most crucial earth-sun connections in this paragraph. Everything that follows refers to this.

The Seasons

Nuclear fusion, a process central to securing future energy supplies, remains a controversial topic due to significant technical challenges. While our ability to replicate fusion is limited, it has been occurring in the sun for at least 4.5 billion years. The sun fuses four hydrogen nuclei to form a helium nucleus, generating approximately 170,000 terawatts of energy across Earth's cross-section, which we perceive as light and heat. In Europe, the sun provides limited warmth during winter but abundant warmth in summer. What causes this seasonal variation?

One might initially suspect that seasonal temperature differences result from Earth's varying distance from the sun during its annual orbit. This assumption has some basis, as Earth's orbit is slightly elliptical, with its closest approach to the sun (perihelion, at 147.1 million kilometers) around January 3 and its farthest point (aphelion, at 152.1 million kilometers) around July 4. However, this variation in distance causes only a 6% difference in solar radiation received by Earth annually, which is insufficient to account for seasonal changes.

The primary cause of seasonal variations is Earth's axial tilt of approximately 23.5° relative to its orbital plane, which shifts the plane of the equator away from a perpendicular alignment with the sun's rays (see Figure 11). As Earth maintains this tilt throughout its orbit, different regions of its surface are inclined toward the sun at varying angles, altering the angle of incidence of solar radiation (see figure 12).

If you own a globe, whether illuminated or not, now is the time to take it out of the corner of your shelf. This globe will come in handy for the upcoming observations.

If we observe the earth-sun system over a whole year from a vast distance, we can distinguish four prominent constellations on the orbit according to the observations made before: At the closest point to the sun, the earth tilts the southern hemisphere towards the sun, and the sun remains perpendicular above the 23.5th parallel south (the solstice on December 21). At a quarter of a turn, the inclination ceases to have any effect; the earth's axis aligns with the sun, resulting in a 90° angle over the equator (the equinox on March 21). A quarter turn further, the northern hemisphere faces the sun at its furthest point from the sun, with the sun perpendicular above the 23.5th degree of northern latitude (solstice on June 21). Following the third quarter turn, we return to the central position, with the sun at 90° above the equator (equinox on September 23). Consequently, in northern summer the rays fall much more steeply in the northern hemisphere than in winter and vice versa in southern summer in the southern hemisphere. And since according to the so-called Lambert's law "the steeper the angle of incidence, the higher the radiation energy reaching the earth's surface, because at a steeper angle of incidence the rays cover a smaller area", it becomes clear why it is so hot in summer. In relation to the earth, the atmosphere's lower filtering effect for the energy-rich short-wave (blue) spectrum at steep angles of incidence contributes to this phenomenon.

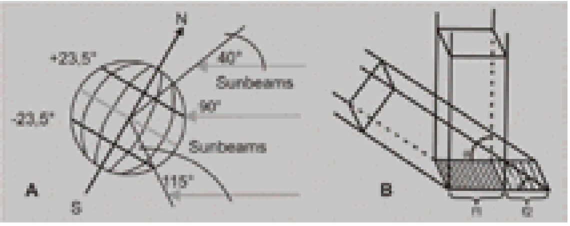

Figure 11: The angle incidence of the sun's radiation in the seasons. The position of the earth in Fig. A corresponds to the northern summer on June 21st. On this date the sun is perpendicular to the Tropic of Capricorn, at an angle of 40° above the North Polar Circle and at an angle of 115° above the Tropic of Capricorn. From the comparison of the areas f1 and f2 and the angles a and ß in Fig. B it can be deduced that the closer the angle of radiation is to 90°, the smaller the illuminated area and the greater the radiation intensity.

Due to the inclined earth axis, the sun apparently wanders over the relatively narrow range between 23.5° northern latitude (its northernmost point and therefore northern tropic) and 23.5° southern latitude (analogous to its southernmost point and consequently southern tropic), and each of the mentioned four positions (the following calendrical data are an arbitrary superimposed plane) marks the beginning of a season.

In the northern hemisphere, winter begins around December 21, when the sun is directly overhead at the Tropic of Capricorn (23.5° south latitude), marking the shortest day and longest night, known as the winter solstice. Spring commences around March 21, when the sun is directly above the equator at the vernal equinox, with both poles equidistant from the sun and day and night of equal length. Summer starts around June 21, when the sun reaches its northernmost point at the Tropic of Cancer (23.5° north latitude), celebrated particularly in Scandinavian countries as the summer solstice, the longest day of the year. Autumn begins around September 23, when the sun, moving southward, is again directly above the equator at the autumnal equinox, with day and night once more equal in length. Thus, each season is defined by either an equinox, when the sun crosses the celestial equator, or a solstice, when it reaches its maximum northern or southern declination.

This explains why tropical regions near the equator experience little

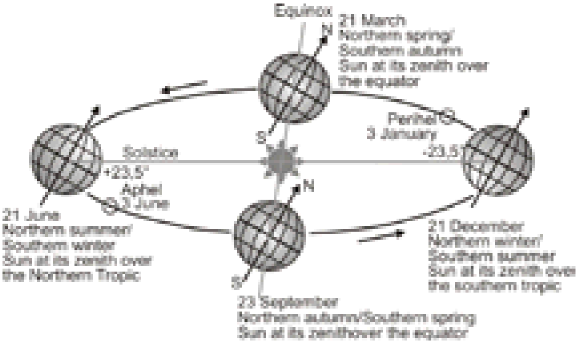

Figure 12: The Earth's Orbit and the Seasons

seasonal variation and have days and nights of approximately equal length year-round. The minimal change in the angle of solar incidence in these regions is insufficient to significantly affect the climate.

These astronomical patterns have shaped human life for millennia, influencing the timing of sowing and harvesting. Our ancient ancestors recorded these cycles in stone circles, creating quasi-calendrical systems to track them.

With the magic of the 23 ½ degrees, the most important connections in the relationship between earth and sun can be explained. They are the measures of perfect symmetry.

The different lengths of day and night

In addition to orbiting the sun, Earth rotates counterclockwise on its axis, resulting in the alternation of day and night as only part of its surface is illuminated by the sun at any given time. This rotation causes celestial objects, including the sun, to rise in the east and set in the west. However, why do summer days lengthen and winter days shorten when Earth's rotational speed remains constant throughout the year? Additionally, why do the sun's rising and setting points shift through the seasons, rendering the saying "In the east the sun rises, to the south it takes its course, in the west it will set, in the north it is never to be seen" accurate only on two days of the year?

These questions are critical for understanding the sun's apparent motion, particularly when planning photography to capture a specific subject, as the timing and direction of sunlight significantly influence the image's effect.

The interplay between the sun's apparent motion—though the sun remains stationary in space—and Earth's actual motion explains both the variation in day length and the shifting sunrise and sunset points, much like the emergence of seasons. As Earth rotates, the sun's apparent path across the sky would correspond to a circle of constant geographical latitude on a globe if the axis were not tilted. However, Earth's axial tilt of approximately 23.5° causes the hemispheres to alternately tilt toward or away from the sun during its orbit. This tilt results in the sun's apparent path, the ecliptic, oscillating north and south of the celestial equator over the course of a year.

The ecliptic, tilted at approximately 23.5° relative to the celestial equator, has its northern half above and southern half below the celestial equator's plane. The points where the ecliptic intersects the celestial equator, known as the vernal and autumnal equinoxes, lie along an exact east-west line. These equinoxes are significant because, during the vernal equinox (around March 21), the sun is directly above the equator, resulting in equal day and night lengths of approximately 12 hours each, with the sun rising due east and setting due west. After the vernal equinox, the sun's apparent path along the ecliptic moves north of the celestial equator, causing its rising and setting points to shift northward. This continues until the summer solstice (around June 21), when the sun reaches its northernmost point on the ecliptic, known as the summer solstice, marking the longest day and shortest night in the northern hemisphere. At this time, the sun is directly overhead at the Tropic of Cancer (23.5° north latitude). Following the summer solstice, the sun's path moves southward along the ecliptic, and the days shorten until the autumnal equinox (around September 23), when the sun is again directly above the equator, rising due east and setting due west. After this equinox, the sun moves south of the celestial equator, resulting in shorter days than nights. This trend peaks at the winter solstice (around December 21), when the sun reaches its southernmost point on the ecliptic, directly overhead at the Tropic of Capricorn (23.5° south latitude), marking the shortest day and longest night in the northern hemisphere. Subsequently, the sun's path shifts northward again, lengthening the days until the vernal equinox, completing the seasonal cycle.

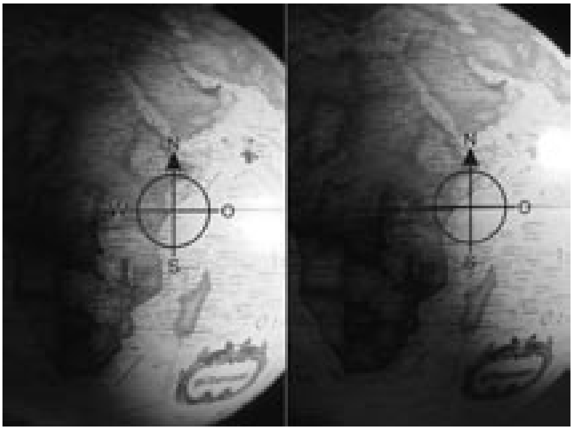

Figure 13: Seasons and day lengths
The image on the left simulates the winter half-year in which the North Pole remains largely in the dark and the southern hemisphere benefits from longer days. The image on the right represents the summer half-year and the opposite case.

The variation in day length between summer and winter results from the fact that, during summer, a larger portion of the sun's apparent path along the ecliptic remains above the horizon compared to winter. This effect is most pronounced at the polar circles, where the phenomena of polar summer and polar winter occur. During polar summer, the sun does not set, and during polar winter, it does not rise. For a visual representation of the sun's apparent path at 66.5° north latitude (the Arctic Circle), refer to Figure 22 in the section "Special

Case: Low Sun Position – The Combined Scattering of Light Produces the Strongest Colors." At the winter solstice, the sun's apparent path remains entirely below the horizon, preventing it from rising. Conversely, at the summer solstice, the sun's path stays entirely above the horizon, preventing it from setting.

To understand the sun's apparent motion, consider a simple analogy. Draw a horizontal line across a sheet of paper, representing the horizon. Place a glass with a wide opening on the line, with half its diameter above and half below. This represents the sun's position during the vernal or autumnal equinox, when it lies on the celestial equator, and its daily path is equally divided above and below the horizon, resulting in equal day and night lengths. Now, shift the glass upward by one-third of its diameter. This simulates the sun's position at the start of summer in the northern hemisphere, when Earth's axial tilt positions the northern hemisphere toward the sun. The sun appears higher in the sky, with more than half of its daily path above the horizon, leading to longer days than nights. Conversely, moving the glass downward by one-third below the midline represents the sun's position at the start of winter, when the northern hemisphere tilts away from the sun, resulting in a lower peak in the sky and shorter days than nights. The sun's apparent path does not actually become steeper in summer or flatter in winter; the angle of its orbital plane relative to the horizon remains constant for a given location. Instead, the portion of the sun's daily path visible above the horizon changes due to Earth's axial tilt. The shifting of sunrise and sunset points is thus a consequence of these dynamics.

Still not convinced by the basic theory? Take a moment and place your globe a few meters away from the sofa. Now you can comfortably observe how the light's glow from the ceiling floodlight in the corner changes on its surface when you tilt its axis toward you, away from you, or parallel to you. See how the North Pole gets some light while the South Pole remains in darkness? Notice how this ratio reverses and how the light is evenly distributed over the sphere in the third position? This is exactly the same on the large scale of reality.