Chapter 1
From the Nuclear Fusion to the Radiated Energy on the Earth

1.1 Inside the Universe

The Sun is the central body of the solar system. It is informally designed as a *yellow dwarf star*. It belongs to spectral type $G2V$ where $G2$ is referred to its temperature surface (approximately 5778 K) and V means that the Sun is a main sequence star and generates its energy by fusion of Hydrogen into Helium. Other GV stars are Alpha Centauri A, Tau Ceti, and 51 Pegasi. It should be noted that the Sun is white, however, it appears as yellow from the Earth for Rayleigh scattering effect through the atmosphere.

The Sun shares the galaxy's rotating motion, moreover, it shows a further rotating motion around its axis that is inclined of $7^\circ\,15'$ on the ecliptic plane. Since the Sun has to be considered as a gas sphere rather than a solid body, the angular speed cannot be constant, it is lower on the poles and greater on the equator, the rotation period is about 25 days.

The Sun is a typical star whose properties have been studied more deeply compared to other stars for the exceptional closeness to the Earth. Fortunately, solar physics coincides with the physics of the great part of our galaxy stars and, with good chance, with that of the great part of the other galaxies.

Due to the turn of the Earth (that is our point of observation) on its axis, to the revolution round the sun and finally to the distance from the Earth to the Sun and from the Sun to the other stars, we experience an apparent motion of the Sun and of the stars. This can be explained by considering that even if stars are always in the same direction from us all the day and all the year (this is the reason for which they are referred as fixed stars), the Sun slightly changes its direction from us all day, from its rising to its setting during the year as a consequence of the Earth revolution around it.

Figure 1.1 shows (not in scale) the fixed stars, the Sun and the Earth with its motion around the Sun in two position named A and B. From the point of observation A, the Sun appears between the Aries and Pisces constellation; a month later with a rotation of $360^\circ/12 = 30^\circ$, the Earth will be situated in the point B and the

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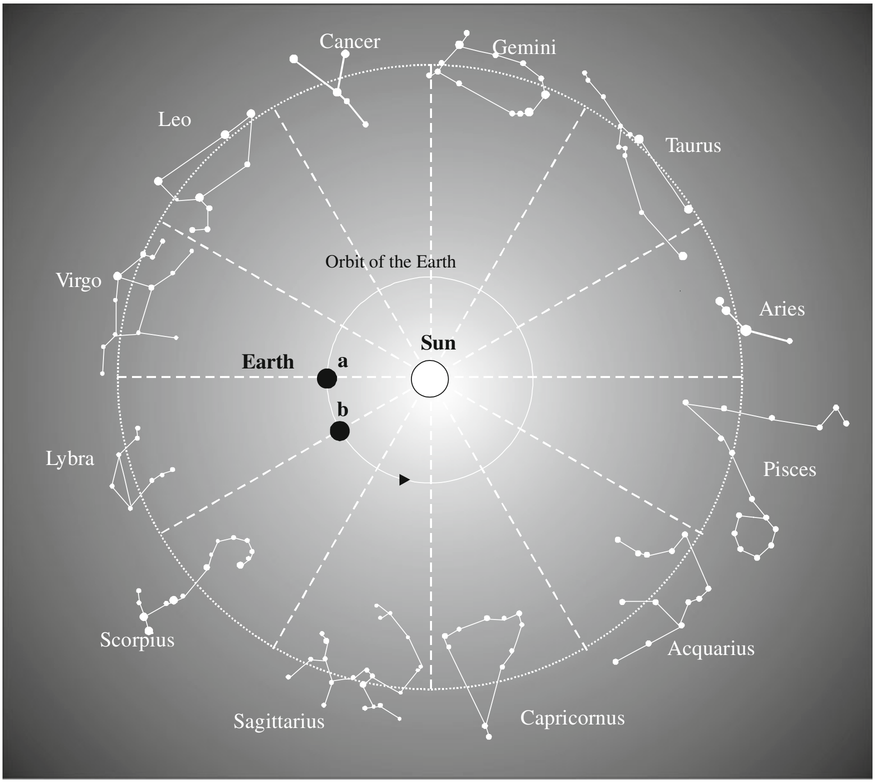

Fig. 1.1 Motion of the Earth around the Sun with constellations on the background

Sun will appear between Aries and Taurus; and so on. As soon as the Earth's rotation will be completed, the Sun will have apparently covered a complete circle around the celestial sphere. The circle thus described by the Sun on the celestial sphere is known as the *ecliptic*.

The ecliptic plane and the plane of the Earth's equator are inclined each other of an angle of 23½°. This inclination is crucial for Earth climate behavior, it defines seasons, it implies that the Sun is higher in the sky (and gives higher sunlight hours) during the summer than during winter.

As it is shown in Fig. 1.2, the ecliptic and the equatorial plane have two points in common that define the Vernal and Autumnal equinoxes.

When the Sun is at the Vernal Equinox, it rises exactly east, and sets exactly west. The days are as long as the nights. In the next 6 months, when the Sun passes from Aries to Virgo it rises north of east and sets north of west; in the northern hemisphere, the days are longer than the nights.

When the Sun passes from Gemini into Cancer, it is on the Summer Solstice, it has reached its greatest north declination and appears at 23.45° N latitude of the equator. Then, it moves toward Libra and there it crosses the equator on Autumnal

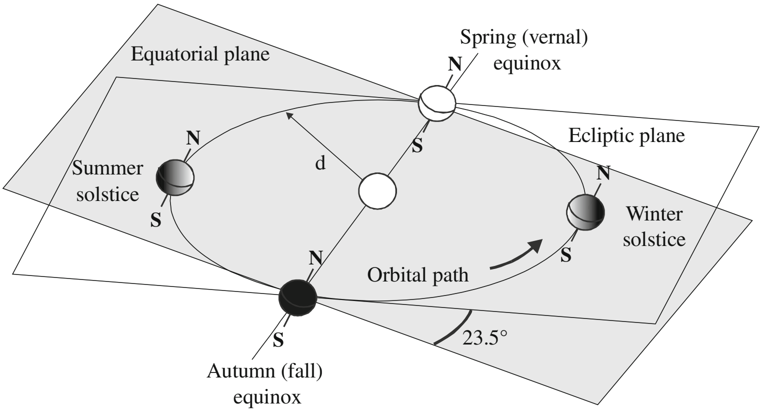

Fig. 1.2 Motion of the Earth around the Sun

Equinox. During the next 6 months the Sun goes from Libra to Pisces, it rises south of east and sets south of west. In the northern hemisphere the nights are then longer than the days. When the Sun passes from Sagittarius into Capricornus, it reaches the Winter Solstice in which it has the greatest south declination, appearing at 23.45° S latitude of the equator and begins to return toward the equator.

The different tracks of the Sun during the year are sketched in Fig. 1.3. It should be noted that in any case the Sun culminates always at south and covers an angular displacement of 15° per hour.

1.2 The Sun

1.2.1 Inside the Sun

The Sun has not exhibited variation in the last billion of years (3×10^{16} s); it means the presence of a force that is opposite to its force of gravity. As a matter of fact the collapse time can be evaluated as ${}^{1}/_{\sqrt{G\bar{\rho}}}$ where G is the Newton's gravitational constant)[1] and $\bar{\rho}$ is the mean density. For G ≈ $6{,}7 \times 10^{-11}$ N (m/kg)^2 and $\bar{\rho}= 1{,}4 \times 10^3$ kg/m^3 the collapse time is lower than 1 h. The antagonist force is due to thermal pressure gradient between its center and the surface. This thermal gradient is sustained by nuclear reaction that converts hydrogen to helium.

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[1] The symbol *G* has been used in Sect. 1.1 to identify the Sun spectral class. It is commonly used for Newton's gravitational constant as well, however, it should not confuse the reader because the context in which the two symbols are used is different. In the next chapters, *G* will denote the solar irradiance and neither the Sun spectral class nor Newton's gravitational constant will be utilized any more.

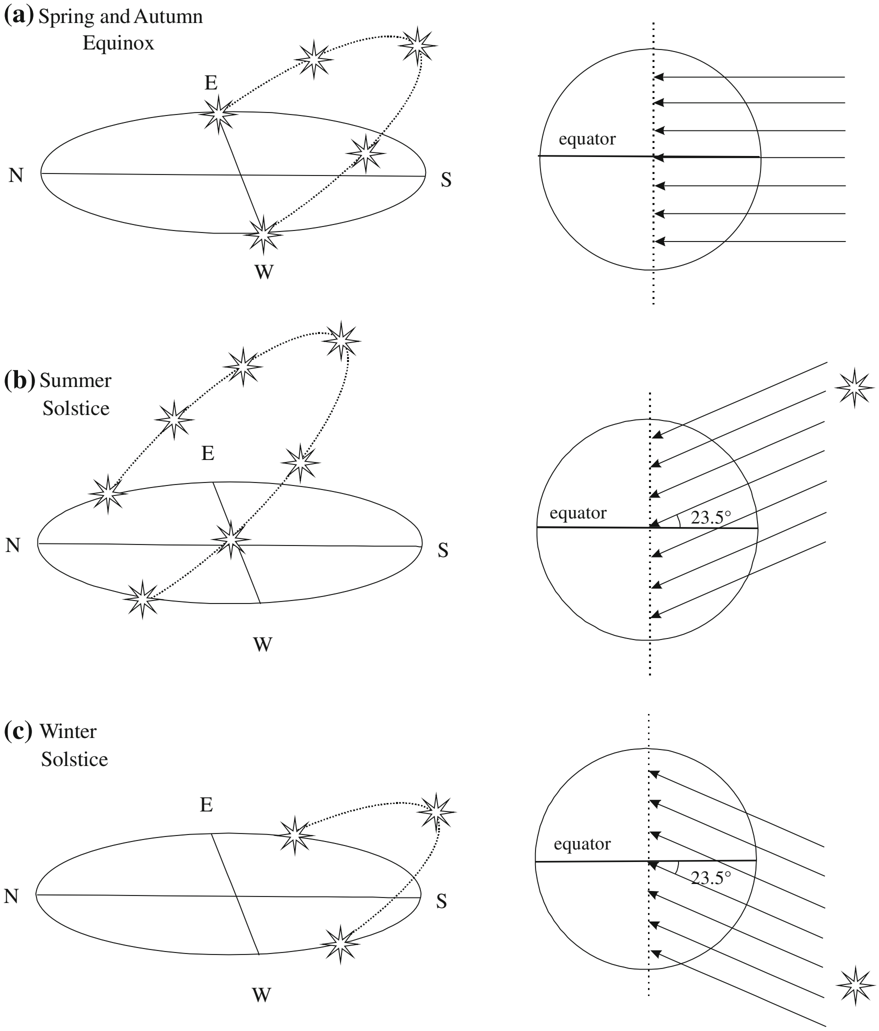
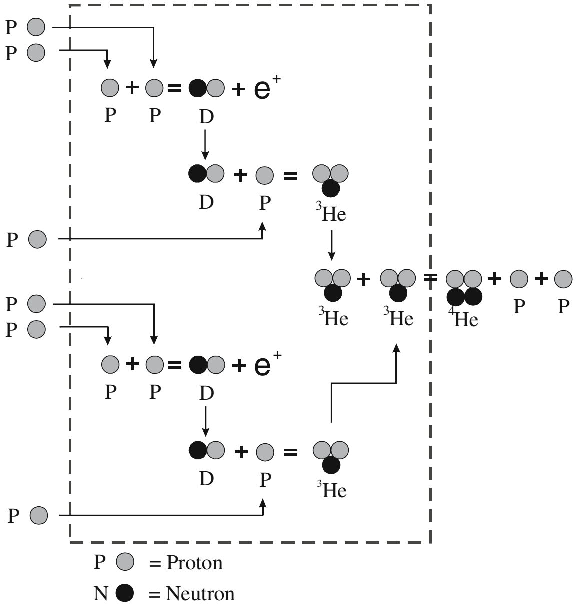


Fig. 1.3 Different positions of the Sun during the year. **a** spring and autumn equinox: the Sun rises at east and goes down at west, day and night have the same length. **b** summer solstice: the Sun rises at north-east and goes down at north-west, days are longer than the nights. **c** winter solstice: the Sun rises at south-east and goes down at south-west, nights are longer than the days. In any case, the Sun culminates at south

As a matter of fact, the Sun is formed by hydrogen (75 %), helium (23 %), and some heavy elements (2 %). Inside the Sun, the nuclear fusion of four hydrogen nuclei (protons) into a helium nucleus occurs.

In particular, first, a couple of protons are transformed into a deuterium nucleus and a positive electron. Then, the deuterium nucleus is aggregated with a proton resulting in a helium nucleus. This last nucleus is formed by two protons and one

Fig. 1.4 Nuclear fusion inside the Sun



neutron and it is indicated as ^{3}He. As soon as this transformation occurs twice, the two ^{3}He nuclei form a helium nucleus with two neutrons or ^{4}He and a couple of protons are obtained.

The whole reaction has six protons as inputs and gives a ^{4}He nucleus and two protons as output. By comparing the mass of the four protons (4×1.00731 amu) where $1 \text{ amu} = 1.66 \times 10^{-27}$ kg, and the mass of ^{4}He nucleus, equal to 4.002063 amu, it can be noted that the resulting mass is reduced by a quantity named the mass defect of the Helium nucleus. The lacking mass has been transformed into energy according to the Einstein's law $E = mc^2$.

Each second, 6×10^{11} kg of hydrogen are transformed into Helium with mass loss of 4×10^3 kg that gives 4×10^{20} J. This energy raises the internal temperature of the Sun up to about 5×10^6 K.

The nuclear fusion steps are drawn in Fig. 1.4.

The temperature decreases toward the surface with a gradient of about 10^{-4} K/cm.

The thermal radiation inside the Sun is not visible, during the way to external surface it is scattered and absorbed. Considering the scattering of free electrons inside the Sun (Thompson effect), the free length path is $\lambda \cong 10^{24}/n$ cm, where n is the density of free electrons equal to 10^{24}. As a consequence ($\lambda = 1$ cm) the Sun appears very opaque. In spite of its low value, the temperature gradient supplies the energy flux against the Sun opacity and maintains the external surface at a temperature of about 5800 K. Now, energy is radiated uniformly in all directions following the Plank's blackbody radiation formula:

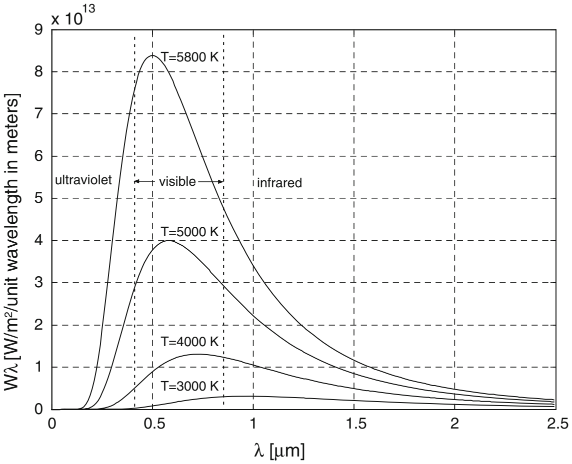


Fig. 1.5 Plank's blackbody radiation versus wavelength for different temperatures

$$\mathrm{W}_{\lambda} = \frac{2\pi hc^2}{\lambda^5\left(e^{\frac{hc}{\lambda kT}} - 1\right)} \tag{1.1}$$

where h is the Plank's constant equal to 6.63 × 10^{-34} J.s and k is the Boltzmann's constant equal to 1.38 × 10^{-23} J/mol·K. It should be noted that Eq. 1.1 is expressed in [W/m^2/unit wavelength in meters], its shape depends on temperature and wavelength. Figure 1.5 shows some different curves representing the Plank's blackbody radiation formula obtained for different values of temperature, T. For T = 5800 K, a great amount of energy is inside the visible spectrum, this gives the characteristic white color of the Sun. Higher temperature implies a blue shift, on the contrary lower temperature gives a red shift. For T = 3000 K, nearly all energy is in the infrared spectrum. This last aspect will be taken again into consideration in Sect. 1.6. Finally, integrating from $\lambda = 0$ to infinity (Eq. 1.1) for T = 5800 K the power density coming from the Sun is obtained; this value, calculated on the outside atmosphere surface, is equal to 1376 W/m^2.

1.2.1.1 How Long Does it Occur?

The value of 1367 W/m^2 before entering into the atmosphere, considering an Earth–Sun distance of 1.5 × 10^{11} m, corresponds to the power supplied by the Sun equal to 3.86 × 10^{26} J/s.

On the other hand, the energy corresponding to the transformation of 1/10 of the Sun's mass, calculated by the Einstein law $E = mc^2$, is equal to 9.2 × 10^{43} J. Hence, the Sun will consume 1/10th of its hydrogen mass within 7,5 billion of years. This last value is greater that the expected life of the Earth. The solar energy, therefore, can be successfully exploited without to be afraid of depletion.

1.2.1.2 Clean Energy Issues

Photovoltaic energy is, without any doubt, a form of clean energy. However, the reader should be borne in mind that it is based on another form of clean energy available by the Sun. As a matter of fact, the nuclear fusion that occurs in the Sun requires a couple of hydrogen nuclei and produces one deuterium nucleus, one electron and releases about 1.4 MeV. This value corresponds to about 2×10^6 times the energy given by combustion of the same mass of coal.

Unfortunately, in normal conditions, two hydrogen nuclei cannot be in touch for the electric repulsion. On the contrary, inside the Sun, the extremely high pressure and temperature conditions make possible this nuclear reaction.

An alternative form of clean energy is given by annihilation in which a couple of particle–antiparticle becomes energy transforming their mass.

Considering, as example, a couple proton–antiproton, annihilation gives an energy equal to $E = mc^2 = 2 \times 1.67 \times 10^{-27}(3 \times 10^8)^2 = 3\ 10^{-10} \mathrm{J} = 1872\ \mathrm{MeV}$. This value is greater compared to that obtained by nuclear fusion of about 10^3.

Both nuclear fusion and annihilation are common in the Universe but improbable on the Earth and it is not foreseeable their exploitation in the next future for energy generation.

1.3 From the Sun to the Earth

Energy coming from the Sun travels for 150×10^6 km before encountering the Earth's atmosphere. Before this it is practically unchanged, but from this boundary several phenomena occur.

Inside the atmosphere, a part of sunlight is absorbed from molecules that raise their own energy. It means that some wavelengths are lessened and the curve of Fig. 1.5 exhibits some hole known as absorption lines. For example, the presence of ozone produces absorption in the ultraviolet region while water vapor and carbon dioxide absorb mainly in the visible and infrared parts of the spectrum.

Scattered sunlight makes blue the sky color and gives us sunlight from north when the Sun is in the south. Without sunlight scattering, the sky would appear black as during the night with the moon. Even with a light shadowing, sunlight is scattered and these rays cannot be focused as the direct rays.

Finally, at ground level, sunlight can be either absorbed or reflected.

Nomenclature for some of the above described situations has been introduced in the literature. The *direct* or *beam* radiation is the sunlight that reaches Earth without scattering while scattered sunlight is defined as *diffuse* radiation. Sunlight reflected from ground is called *albedo* radiation and the sum of direct, diffuse, and albedo radiation is the *global* radiation.

It is clear that the path length through atmosphere plays an important role in the spectrum of sunlight at Earth level. Conventionally, the vertical path length directed to the sea level is defined as *air mass* = 1 (AM1). If Sun rays are inclined,

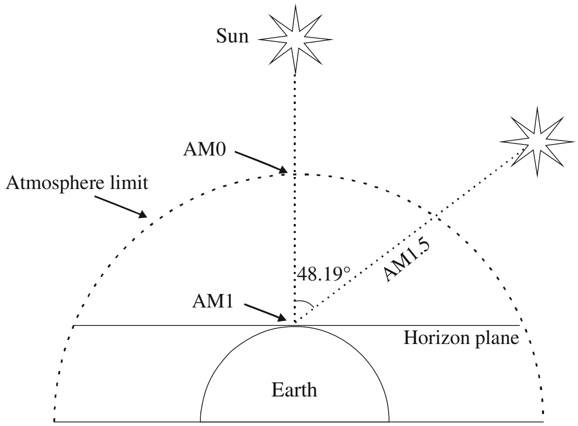


Fig. 1.6 Different values of AM vs. solar position

the AM value is greater than one. Considering the absorption at AM1, the power density coming from the Sun is diminished of about 70 %; it is slightly greater than 1000 W/m^2.

The ratio of monthly average daily total horizontal insulation on the Earth's surface $\bar{H}$ to the monthly average daily total horizontal insulation outside the atmosphere $\bar{H}_{\mathrm{ext}}$ is defined as *clearness index* K_T. It is a value that varies with the place and during the year. It includes the effects of the weather, diffuse, reflected direct radiation as well.

$$K_T = \frac{\bar{H}}{\bar{H}_{\mathrm{ext}}} \tag{1.2}$$

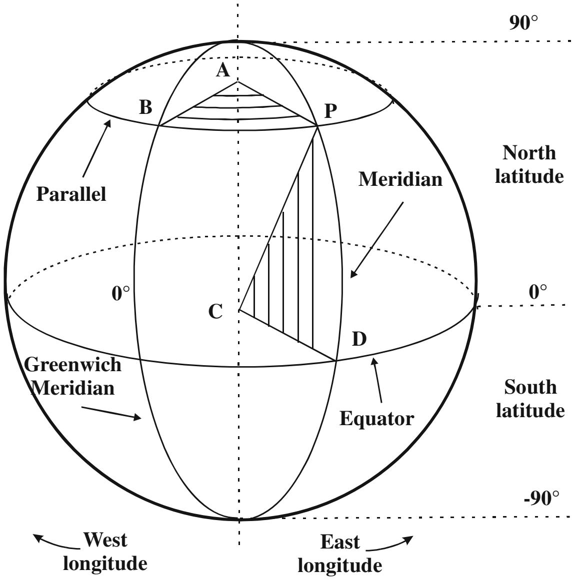
For AM different from unity, power density I [W/m^2] can be deduced by:

$$I = 1367(0.7)^{\mathrm{AM}^{0.678}} \tag{1.3}$$

The value of AM1.5 is used as a standard calibration spectrum for photovoltaic cells. It corresponds to the spectrum obtained when the Sun forms an angle of 48.19° with the line perpendicular to the earth in the considered point. Figure 1.6 shows different values of AM.

If photovoltaic performance is evaluated under conditions that differ from AM1.5, a calibration factor must be adopted. In general, this correction factor gives the short-circuit current taking into account environmental conditions as AM and water vapor and turbidity. It should be borne in mind that the calibration factor value is influenced by the semiconductor used to set up the photovoltaic generator, for example amorphous silicon has a much higher sensitivity to water and turbidity than crystalline Si, CdTe, or CuInSe$_2$. In any case, the calibration factor is more accurate for conditions near to AM1.5.

Fig. 1.7 Representation of latitude and longitude



1.3.1 Finding One's Bearings on the Earth

The Earth seen by the Sun appears always as a dot. However, the effects of the Sun are very different depending on the point of observation on the Earth surface where a dedicate coordinate system is fundamental to define the position and the related effects tied to solar radiation.

Two parameters have to be introduced: latitude and longitude.

Latitude (abbreviation: Lat., φ, or phi) is the angle between the equatorial plane and a line that is normal to the reference ellipsoid, which approximates the shape of the Earth. The loci of the points with the same latitude are called *parallels*. Parallels trace circles on the surface of the Earth, parallel to the equator. Conventionally, the north pole is 90° N; the south pole is 90° S. The equator defines 0° parallel and the fundamental plane of all geographic coordinate systems. The equator divides the globe into Northern and Southern Hemispheres.

The half circles joining the two poles that cut perpendicularly the equator are defined as *meridians*. A line passing to the rear of the Royal Observatory, Greenwich (near London in the UK) has been chosen as the international zero-longitude reference line, the Prime Meridian.

Longitude (abbreviation: Long., λ, or lambda)[2] is the angle east or west of a reference meridian between the two geographic poles to another meridian that passes through an arbitrary point. All meridians are halves of great circles, they converge at the north and south poles. Places to the east are in the eastern

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[2] The Longitude symbol should not be confused with the wavelength.

hemisphere, and places to the west are in the western hemisphere. The antipodal meridian of Greenwich is both 180°W and 180°E.

The latitude/longitude "webbing" is known as the conjugate graticule. Figure 1.7 shows a representation of latitude and longitude on the Earth.

1.3.2 The Greenhouse Effect

Energy received by Earth during the day is re-radiated during the night into space. For maintaining its constant temperature, a thermal equilibrium is necessary. However, the Earth has a mean temperature of 300 K, hence it can reradiate at long wavelength compared to the Sun. The atmosphere has a crucial role in this equilibrium. It should be borne in mind that, without atmosphere (like on the moon), the Earth's temperature would fall about 255 K, corresponding to -18 °C. With the atmosphere, a natural background of 270 ppm of CO_2 maintain the mean temperature of 300 K.

The balance can be compromised by "greenhouses gases" as carbon dioxide, methane, and chlorofluorocarbons (CFCs) that are mostly transparent to Sun's wavelength but, absorbing the short wavelength radiation, prevent Earth to reradiate during the night. As a consequence, Earth's temperature rises; this phenomenon is known as global warming or greenhouse effect.

1.4 Tracking the Sun

As soon as solar energy has reached the Earth, the target is to use the greatest possible part of it to produce energy under other form as electric energy.

As it is shown in the above sections, the Sun position and height are continuously varying during the day and during the year and depend on the position of the observer.

To this aim a mathematical description of the motion of the Sun has to be set up.

The power density of sunlight is defined as *irradiance.* The irradiance received by the Earth from the Sun at the top of the atmosphere (AM0) is defined as *solar constant* and it is equal to 1367 W/m^2.

The energy density of sunlight is defined as *irradiation* and it is expressed in [kWh/m^2]. The irradiation is obtained by integrating the irradiance over time, usually the time interval of integration is referred to one day and it is performed on daylight hours. Another way to express irradiation consists on *peak sun hours* (psh). It is the time interval, in hours, that is necessary to an irradiance of 1 kW/m^2 to produce the daily irradiation obtained by integrating the real irradiance over the daylight hours of the same day. The daily irradiation is numerically equal to the daily psh.

Figure 1.8 shows the irradiance plot measured in a real situation (photovoltaic plant located at 38°06′15.17″ N, 13°20′49.24′ E.) and corresponding irradiation. It

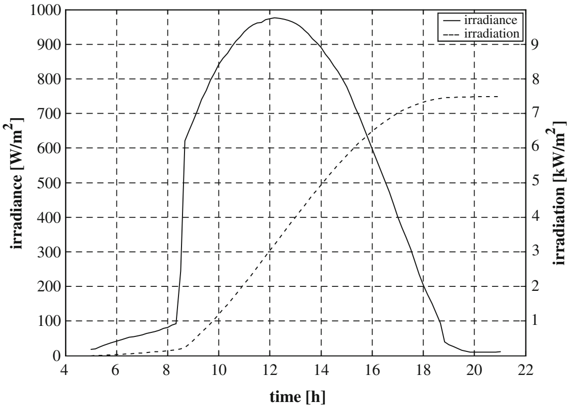


Fig. 1.8 Irradiance and irradiation plot

should be noted that the typical "bell shaped" curve is deformed due to the presence of a wall.

With reference to Fig. 1.2, the distance from the Earth to the Sun d [m] can be described by Eq. 1.4 that represents an elliptic orbit with the Sun placed in one of the foci.

$$d = 1,5 \times 10^{11} \left\{ 1 + 0.017 \sin\left[\frac{360(n-93)}{365}\right] \right\} \tag{1.4}$$

The parameter n represents the number of the day, where the first of January is set for $n = 1$. It should be noted that the distance varies slightly, as a consequence its mean value of 1.5×10^{11} m is assumed as the distance.

The angle formed by a line from the center of the Earth to the Sun and the equatorial plane is defined as *declination* δ. The declination, whose value is null on Spring and Autumn equinox, is equal to 23.45° on Summer solstice (assuming as positive angles in north direction respect to the equator) and it is equal to −23.45° on Winter solstice.

During the year the declination varies as:

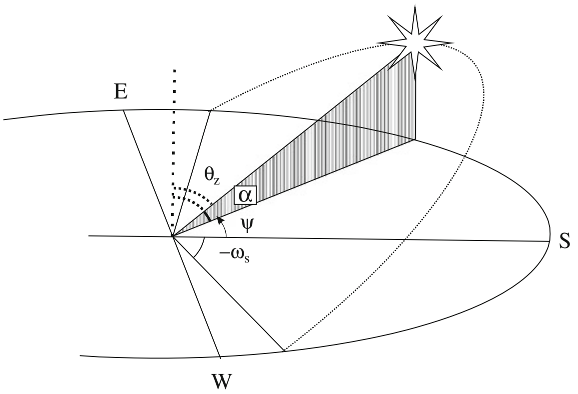
$$\delta = 23.45^\circ \sin\left[\frac{360(n-80)}{365}\right] \tag{1.5}$$

Even if Eq. (1.4) is an approximation (the year is assumed 365 days long and $n = 80$ is the first day of Spring), it can be used successfully.

A line perpendicular to the Earth is defined as *zenith*. The zenith angle θ_z is the angle between a straight line passing from the center of the Earth to the Sun and the zenith.

The *solar noon* is defined as the time in which the Sun is at its highest point in the sky. For given time zone, solar noon occurs at 12 only for one point at a given latitude; at longitude east (west) of this point solar noon occurs before (after) 12. It can be noted from Fig. 1.3 that at solar noon a shadow points directly to north or south, depending on latitude.

Fig. 1.9 Representation of solar angle and azimuth



The latitude and declination are related to the zenith angle at solar noon by the following relationship:

$$\theta_z|_{\text{solar noon}} = \phi - \delta \tag{1.6}$$

where ϕ is the latitude and δ is the declination.

Several information can be deduced by Eq. 1.6. It depends on the place by means of latitude and on the day of the year by the declination. $\theta_z|_{\text{solar noon}} = 0$ for $\phi = \delta$, but being $-23.45° \leq \delta \leq 23.45°$ only places with $-23.45° \leq \phi \leq 23.45°$ will be able to see the Sun on a straight line perpendicular to the Earth in a day of the year. Moreover, if $\theta_z|_{\text{solar noon}} \leq 90^{\circ}$ the highest point falls below the horizon and there will be no sunset. It can occur if $\varphi \leq -66.55°$. In particular in the south pole where $\phi \cong -90°$ for $0 \leq \delta \leq 23.45°$(from Spring to Autumn equinox) six months of darkness are expected.

The *solar altitude* α is defined as the angle formed by the horizon and a straight line connecting the Earth and the Sun in a plane perpendicular to horizon. The solar altitude is complementary to the zenith angle.

The *azimuth angle* ψ is the Sun angular position east or west to south. Conventionally, azimuth is null at solar noon and it increases toward the east. However, some papers refer the azimuth to north, in such case at solar noon $\psi = 180°$. Figure 1.9 gives a representation of solar angles and azimuth.

The same information given by azimuth can be expressed by *hour angle* ω as the difference between noon and the time. Considering a rotation of 360° in 24 h

$$\omega = \frac{12 - \text{time}|_{24\,\text{h}}}{24} 360 = 15(12 - \text{time}|_{24\,\text{h}}) \tag{1.7}$$

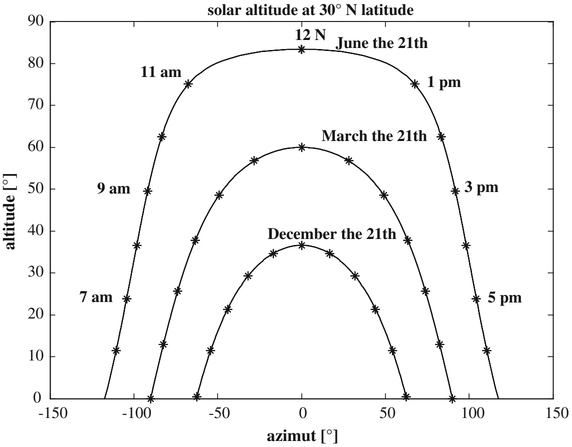
where $\text{time}|_{24h}$ is the time referred to solar midnight on a 24-h clock.

The sunrise angle can be deduced by knowing the latitude and declination by:

$$\omega_s = ar\cos(-\tan\phi\tan\delta) \tag{1.8}$$

and the sunset angle is given by $-\omega_s$

Fig. 1.10 Solar altitude versus azimuth angle during the year at a latitude of 30° N



By observing that in a day from sunrise to sunset the displacement angle is equal to $2\omega_s$ and that a complete rotation requires 24 h, it is possible to calculate the daylight hours DH

$$DH = \omega_s \frac{48}{360} = \frac{ar\cos(-\tan\phi\tan\delta)}{7.5} \tag{1.9}$$

Finally, the position of the Sun can be obtained using the solar altitude and the azimuth angle versus latitude, declination, and hour angle.

$$\sin\alpha = \sin\delta\sin\phi + \cos\delta\cos\phi\cos\omega \tag{1.10}$$

$$\cos\psi = \frac{\sin\alpha\ \sin\phi - \sin\delta}{\cos\alpha\ \cos\phi} \tag{1.11}$$

It should be remembered that all angles are expressed in degrees.

Solar altitude versus azimuth angle during the year at a latitude of 30° N and 65° N are respectively sketched in Figs. 1.10 and 1.11, by comparing these figures, the different Sun altitude can be noted.

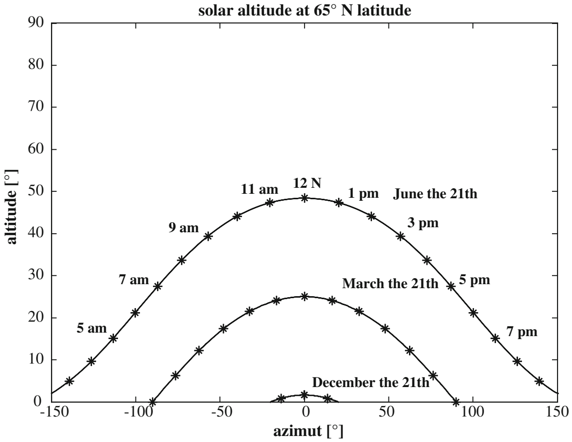
1.5 Measuring Sunlight

In Sect. 1.4, it has been explained how irradiance can be predicted versus day of the year and latitude. Irradiance can be also measured with dedicated systems. The advantages consist, for example, on taking into account the real irradiance value in that moment to maximize the collected energy.

Precise sensors are: the pyranometer and the pyrheliometer.

The pyranometer measures global radiation. It can be mounted horizontally or on the collector surface. In this last case, it measures global irradiance perpendicular to

Fig. 1.11 Solar altitude versus azimuth angle during the year at a latitude of 65° N



the collector. On the outside, there is a lens that is transparent for wavelength from 0.285 to 2.8 μm. The sensor is a circular multijunction, wire–wound thermopile, it has as accuracy of 1 % for altitudes higher than 20° and its output voltage is 9 μV/W/m^2.

The black and white pyranometer is less accurate and operates on the basis of different heating of black and white wedges. Each wedge has a thermocouple that measures temperature and a voltage dependent on temperature difference is given as output.

The normal incidence pyrheliometer operates on the basis of the collected beam irradiance into a small solid angle (about 5.5°). It is obtained by means of a tube blackened inside. The tube is sealed with dry air to eliminate absorption of incident beam by vapor. The sensor is a wire–wound thermopile and its sensitivity is about 8 μV/W/m^2. To perform continuing measurements a tracker is needed.

In order to measure diffuse component of irradiance, a pyranometer can be used with a shadow band stand.

Finally, some less precise and cheaper measurement systems exist as cadmium sulfide photocells and silicon photodiodes. These devices are not sensitive to the whole solar spectrum and cannot be calibrated to measure total energy.

1.6 Sunlight Emulation

In Fig. 1.5, it has been highlighted that a blackbody radiation corresponding to 3000 K falls mainly in the infrared spectrum. This is the typical case of incandescent lamp filaments. It has been demonstrated that these kind of lamps have a poor efficiency as lighting systems, moreover they are unable to emulate sunlight due to their different spectrum compared to the Sun.

Other lighting systems as gas discharge lamps differ from blackbody radiation due to presence in their spectrum of characteristic lines of the adopted gas, as in the case of fluorescent tubes, high pressure sodium, and high intensity discharge lamps.

As it will be described in the following chapter, a photovoltaic device can generate electricity depending on the energy received under form of radiated waves. As a consequence, standardized spectral test condition has to be defined in order to evaluate the goodness of photovoltaic generator.

1.7 Collecting Sunlight

Once arrived on the Earth, it is necessary to optimally collect sunlight before transforming it into electric energy. The best situation is to have the collector orthogonal to beam, unfortunately, as it has been described before, the Sun's position varies continuously during the day and day of the year.

Under the hypothesis of a fixed collector, a good choice can be done considering that at solar noon the Sun will be perpendicular to a collector which forms an angle of θ_z with the horizon plane (tilt angle). In this situation the Sun is highest in the sky and lowest AM is obtained. Considering that the Sun covers 15° per hour, the optimal position will be maintained for about 2 h. A satisfactorily efficiency, however, is assured between 10 a.m. and 2 p.m. as shown in Fig. 1.9 and 1.10. It should be noted that the use of Eq. 1.6 implies the choice of a declination value. A mean value referred to the season can be adopted. If, for example, best performance is expected during the summer on northern hemisphere, using Eq. 1.5 a value of $-14.93°$ is obtained which implies that the collector has to be mounted at about $\varphi - 15°$

Some installations could require different orientation. For example, in a grid connected plant, collected energy has to be maximum when the consumer request is higher and it occurs after solar noon. In this case, hence, a west facing orientation shifts the peak of collected energy toward afternoon.

Of course, the collector can have one o two degree of freedom to track Sun beam. In general, efficiency gain is greater in summer rather than in winter. Moreover, increased cost and energy required to tracking system have to be taken into account by designer.

In presence of diffused sunlight, the beam irradiance is a small fraction of the global irradiance.

1.8 Conclusions

Energy is created by nuclear fusion process into the Sun: four hydrogen nuclei are transformed into a helium nucleus, the whole mass is decreased and this lack becomes energy radiated into the universe. This energy reaches the Earth, it is partially scattered by the atmosphere, and it can be utilized to be converted into electric energy by photovoltaic devices.

Through this chapter, the energy generation process, how it can be tracked, collected, and measured to be transformed and utilized as electric energy are explained.

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