CHAPTER 1

The Sun

The naked eye stars in the sky is called celestial sphere. The sun is one of the normal sized star in the milky way galaxy. The galaxies are the building blocks of the universe. There are about 10 billion (10^9) galaxies in the universe. The milky way galaxy is rotating around its nucleus in accordance with law of gravitation. The distance of the sun from the galactic centre is about 30,000 light years. (1 light year = distance travelled by light in one year. Speed of the light = 3×10^8 m/s; 1lt yr = $365.25 \times 24 \times 60 \times 60 \times 3 \times 10^8$ m/s $\simeq 9.5 \times 10^{12}$ km). The link between the distant stars and the earth is the electromagnetic radiation emitted by the stars. The radiation emitted by the stars enables us to detect its source of direction, its composition, temperature and its velocity towards the earth or away from it (Doppler effect).

***Big Bang theory*:** All matter in the universe initially was packed in a compact superdense agglomeration. It was hurled in all directions with a cataclysmic explosion (called Big Bang). Since then the mass is moving away from that nuclear centre and the universe is expanding. The recession of the galactic mass depended on the initial velocity, higher the velocity of matter farther is its recession.

***Solar System*:** The sun is at one of the foci of the ellipse. All planets, including the earth are revolving in elliptical orbits around the sun. The solar system as a whole is rotating and moving in the milkyway galaxy with a velocity of about 400 km/s; which is the absolute velocity of the sun. The origin of the solar system is very complex and still obscure.

***The Sun*:** The mass of the sun is about 1.99×10^{30} kg, its radius is about 6.97×10^8 m (or diameter = 14×10^5 km). The mass of the earth is about 6×10^{24} kg, its radius about 6.4×10^6 m. The gravitational attraction of the sun is about 274 m/s^2, while the gravitational attraction of the earth is about 9.81 m/s^2. About 99.87% mass of the solar system is contained in the sun (see Fig. 1.1). The mean earth-sun distance is 150×10^6 km.

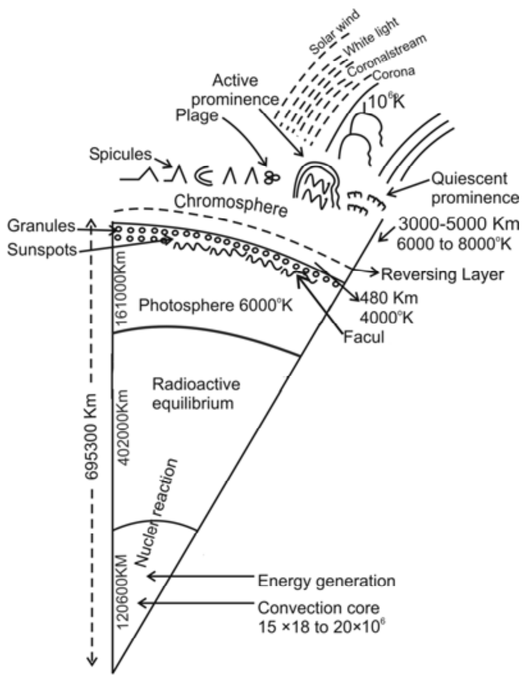

Fig. 1.1 Schematic representation of structure and activities of the sun with the exaggerated photosphere, chromosphere.

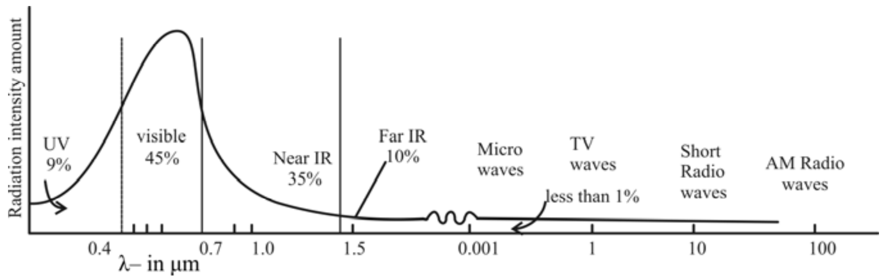

Fig. 1.2 Sun's electromagnetic spectrum, not to scale.

Photosphere**:** The visible surface of the sun is called photosphere, its temperature is about 6000 ^{o}K. The photosphere consists of hot gases under high pressure. Photosphere produces radiations of the visible part of the solar spectrum, but the energy is produced in the deeper central region of the sun's sphere. The surface of the sun changes constantly without any rhythm. It appears as mottled or granular due to the boiling motion of the gases. The granules are visible to naked eye. Besides granules the photosphere shows bright regions called faculae and dark (cold) regions called sunspots. Sunspots are regions of strong magnetic field.

Chromosphere**:** During the total solar eclipse a reddish ring of light observed around the sun's photosphere, which is called chromosphere or the colour sphere of the sun. It consists of hydrogen and helium gases at low pressure, but has temperature about 20,000 ^{o}K. Fibrilles and spicules are observed in the chromosphere. In chromosphere temperature rises slowly from 4400 ^{o}K to about 1.5 to 2.0 million ^{o}K. Between photosphere and chromosphere there is a cooler gas layer with temperature about 4000 ^{o}K, thickness about 500 km. This is called reversing layer. Above this layer temperature rises.

Corona**:** Above chromosphere lies corona, which spreads far out into space with temperature 1.5 to 2.0 million ^{o}K. During total solar eclipse corona shows spectacular light of halo. Solar winds originate in corona, whose speed exceed 100 km/s and the plasma particles of corona exceed the escape velocity of the sun's atmosphere. This is called solar wind and it depends on the solar activity.

Solar Activity**:** when the frequency of observable features of the sun (such as sunspots, solar wind, solar flares) are more than normal, then sun is said to be active or "disturbed", but when they are absent the sun is said to be "quiet". As seen from the sunspots the solar activity has about

11 years cycle. Sunspots begin to appear at latitude 35^o on both hemispheres of the sun, this is sunspot minima phase. As the cycle advances, the number of spots increase in size and numbers and spread to the solar equator, which is sunspot maxima phase. Subsequently these spots decrease gradually and disappear. Again a new cycle begins with sunspots reappearing at latitude 35^o. Sunspots are regions of cooler temperature and lower energy. The other observable features where energy emission is more than normal are called active regions. A facula appears before sunspot and persists even after the visible appearance of the spot. Faculae are also observed at high latitudes of the sun in the absence of sunspots.

Increased solar activity is seen in chromosphere in association with the sunspot groups in photosphere. Large bright regions are called plages.

Sometimes clouds of bright gas is seen projecting outwards from chromosphere, which are called prominences. When rapid changes are observed in the neighborhood of prominences there appears chromospheric bursts, coronal rays and holes.

The magnetic field in sunspots observed to exceed thousand times as compared to the magnetic field outside the sunspots. The polarity of the magnetic field in sunspot area changes in 22 years, which is twice the period of sunspot cycle. There does not appear to be a clear cut theory of solar activity. No sunspots observed during 1645 to 1715 (70 years) and there does not appear 11 year sunspot cycle before 1645. These facts were brought to the light by E. Maunder, the superintendent of Greenwich observatory in 1890. The 70 year period (1645-1715) of sunspot minima or complete absence of it, is called Maunder Minima.

***Cosmic Rays*:** The high energy particles of the galactic origin (outside the solar system) are called cosmic rays. The solar activity influences the intensity of cosmic rays that are falling on the earth. Cosmic rays propagate along the galactic magnetic field and are deviated by the earth’s magnetic field (Moon has no magnetic field and has no radiation belts around it). During quiet sun, the solar wind is weak, and as a result magnetosphere shrinks and allows the cosmic rays to penetrate to the earth.

The sun’s thermal radiation remains constant and is not affected by the solar activity but it effects short wave radiation (λ – less than 0.1 μm).

The effect of sun's gravity on earth's biosphere is insignificant compared to the gravity of the earth itself.

***Central Core*:** The central core of the sun has temperature 15 to 20 million ^{o}K. Above this convective core there is a radiative equilibrium layer with temperature ranging 10 million ^{o}K to 6000 ^{o}K. The convective core and radiative equilibrium region is characterized by nuclear reactions, which is the source region of solar radiative energy.

***Solar Flares*:** The solar flares are the result of gigantic nuclear explosions in the central core. Solar flares are the most spectacular activity of the charomosphere, but short lived (short period of life). There may be hundred odd flares daily but a few large flares may occur in a year. The large flares emit electromagnetic radiation and high energy charged particles of plasma. These particles may have velocity about 10 km/s. The Plasma particles consists of 91% ionized helium, which on reaching the earth interacts with atmosphere and earth's magnetic field. It causes ionospheric storm (high frequency radio blackout) and magnetic disturbances. The Solar wind associated with flare may have velocities 300-800 km/s.

***The Hetrogeneous Rotation of the Sun*:** Unlike the earth (which has all particles same angular velocity), the gaseous globe of the sun rotates a full turn at its equator in 25 days, and at its pole in 35 days. This rotation is called differential. The angular velocity of the sun's rotation also changes with depth, however the convection of the sun, its magnetic field and differential rotation are all related and interact with one another. The north pole of the sun is seen on the earth between 7 June to 7 December and the south pole of the sun is seen 8 December to 6 June.

Sun's Electromagnetic Spectrum

The temperature of sun's gases in photosphere has more than 6000 ^{o}K, which produce electrically charged particles with different speeds. As a result of their collision, electromagnetic waves of different wavelengths are emitted by the sun. These waves constitute the electromagnetic spectrum of the sun (see Fig. 1.2) which extends from gamma rays ($\lambda = 10^{-13}$) to radio waves ($\lambda = 10^{3} m$). The total range of λ is 10^{16} m.

About 99% of the solar radiation lies between $\lambda = 0.15$ to 4.0 μm, the distribution is as follows:

(i) About 9% of this lies in UV-radiation $\lambda = 0.15\mu m$ to 0.38 μm. This causes photochemical effects, bleaching and sunburn etc.

(ii) About 44% of this lies in visible portion, λ = 0.38 μm to 0.7 μm (that is violet to red).

(iii) A bout 46% lies in infrared region, λ = 0.7 μm to 2.3 μm. This causes radiant heat with some chemical effects.

All these radiations travel with a speed of 3×10^8 m/s in vacuum.

According to Wien's law

$$\lambda_{max} = \frac{\text{constant}}{T} = \frac{2897\mu\text{mK}}{T}$$

or

$$\lambda_{max} \simeq \frac{3000\ \mu\text{mK}}{T}$$

Sun emits energy at an average temperature of 6000 ^{o}K, while earth emits at an average surface temperature of 15 ^{o}C or 288 ^{o}K. It follows that, for sun $\lambda_{max} = \frac{3000\ \mu m\text{K}}{6000\ \text{K}} = 0.5\ \mu m$, that is the sun emits maximum radiation energy at wave length $\lambda_{max} = 0.5\ \mu m$.

For the earth

$$\lambda_{max} = \frac{3000\ \mu\text{m K}}{288\ \text{K}}$$

$$\simeq 10\ \mu\text{m} \qquad (\text{taking } 288^{o} \text{as } 300^{o}\,\text{K})$$

That is, the earth emits maximum amount of radiant energy at wavelength λ_{max} = 10 μm.

Because of these facts the terrestrial radiation is called long wave radiation and solar radiation is called shortwave radiation.

It is estimated that in all sun radiates each minute about 56×10^{26} cal of energy.

***Solar constant* (S):** The amount of solar radiation (energy) incident on unit area in unit time on a surface held at right angle to the solar beam at the outer boundary of the atmosphere is called solar constant and is given by

$$S = 2.0 \text{ ly/min or } 1359 \text{ W/m}^2,$$

where 1 ly (one Langley) = 1 cal/cm^2

The total solar energy intercepted by the earth in unit time = $\pi R_e^2 S$

where R_e = Radius of the earth.

This energy if spread uniformly over the whole of the earth, then the amount of solar energy received on unit area of the earth in unit time at the top of the atmosphere (Q_s) is given by

$$Q_s = \frac{\pi R_e^2 S}{4 \pi R_e^2} = \frac{S}{4} = 0.5 \text{ ly / min}$$

$$= 263 \text{ kly/year} \qquad \text{(kly = kilo Langley)}$$

$$= 339.75 \text{ W/m}^2$$

On an average the mean cloud coverage of the earth is slightly more than 50 %. Under this condition the distribution of insolation (incoming solar radiation) is given in Fig. 1.3.

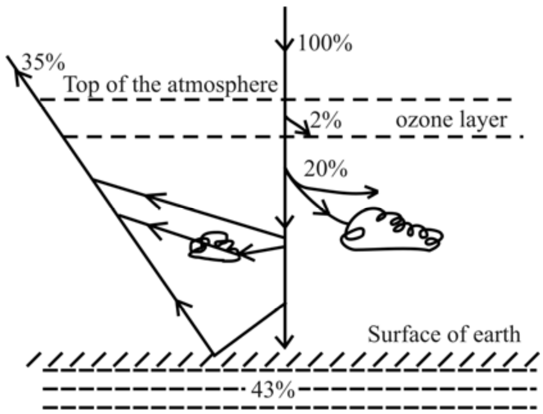

Fig. 1.3 Disposition of insolation in earth atmosphere.

Reflection and back scattering 35% ($\simeq$ 92 kly/year)

Absorption by ozone 2 % ($\simeq$ 5 kly/year)

Absorption by clouds, water vapour, dust etc 20 % (53 kly /year)

Absorption by the earths surface 43 % (113 kly / year)

The earth-atmosphere together absorb 65 % (171 kly / year)

Radiative Balance and Horizontal Transport of Heat

Past available records show that the global average of earth's surface temperature is about 15 ^{o}C and it is virtually constant. It means the amount of heat energy that is received by the earth (mainly in the form of shortwave radiation is equal to the amount of heat energy that is lost by the earth (by way of long wave IR-radiation). On the whole the earth atmosphere system radiates back nearly the same amount of energy that it is receiving from the sun. However the latitudinal distribution of incoming solar radiation to the earth and the outgoing radiation from the earth are different (that is they are not equal, see Fig. 1.4).

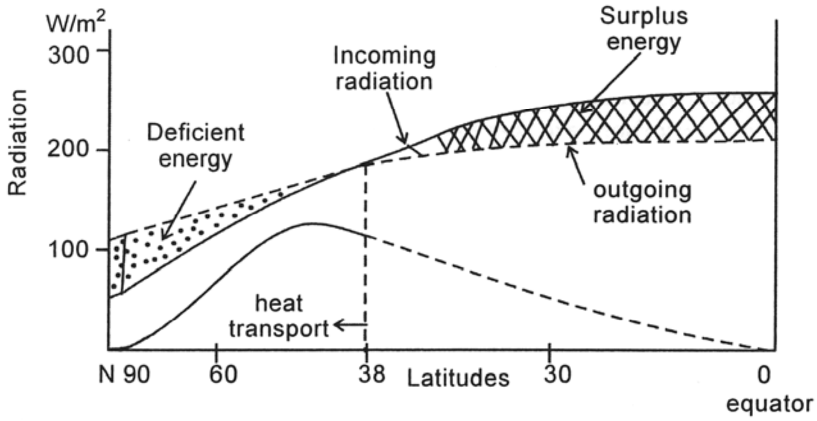

Fig. 1.4 Mean radiation balance northern hemisphere, solid line incoming solar radiation, dotted line outgoing earth radiation.

The Fig. 1.4 shows that in the equatorial region more energy is absorbed than that emitted by the earth. The earth-atmosphere system shows that there is surplus energy between latitudes 0^{o}-35^{o} (area hatched with cross lines), while more energy is emitted by the earth to space than received between latitudes 35^{o} to 90^{o}, indicating deficient energy in these latitudes (area hatched with dots). Since the earth as a whole is neither becoming warmer nor cooler shows that the excess energy absorbed in low latitudes is transported to higher latitudes, (otherwise equatorial regions would have much higher temperatures and mid and higher latitudinal regions would have been cooled to **very** low temperatures). This transfer of heat from lower to higher latitudes is carried by the action of wind and ocean currents. It has been calculated that ocean currents carry about 30% required heat transport from equator to polewards.

Questions

1. The temperature of the suns photospheric gases is about
   (a) 600^{o}k (b) 6000^{o}k (c) 60000^{o}k (d) None
2. The global average temperature of the earth is about
   (a) 10^{o}C (b) 15^{o}C (c) 20^{o}C (d) None
3. The sun emits maximum radiation energy at wavelength(λ):
   (a) 0.5 μm (b) 1 μm (c) 10 μm (d) None
4. The earth emits maximum radiation energy at wave length(λ)
   (a) 1 μm (b) 10 μm (c) 20 μm (d) None
5. Most of the insolation lies in:
   (a) Short wave radiation (b) Long wave radiation
   (c) UV radiation (d) None
6. Mean cloud coverage of the earth is
   (a) Slightly less than 25%
   (b) Slightly more than 50%
   (c) Slightly less than 75%
   (d) Slightly more than 90%
7. Most of the earth-atmosphere radiation lies in
   (a) Short wave radiation (b) Long wave radiation
   (c) UV radiation (d) None
8. In equatorial region (between latitudes $0–35^{o}$):
   (a) More energy absorbed than emitted back to space
   (b) Less energy absorbed than emitted back to space
   (c) Energy absorbed is equal to the energy emitted back to space
   (d) None
9. In middle and higher latitudes (between $35–90^{o}$)
   (a) More energy absorbed than emitted back to space
   (b) Less energy absorbed than emitted back to space
   (c) Energy absorbed is equal to energy emitted back to space
   (d) None

10. At the surface (and in lower troposphere) heat transport takes place:
    (a) From poles to equator ward
    (b) From equator to pole wards
    (c) No heat transport takes place
    (d) None above
11. In troposphere at about 8 km. altitude level (and above)
    (a) Equatorial regions are warmer than polar regions
    (b) Equatorial regions are cooler than Polar Regions
    (c) Equatorial region and Polar Regions have the same temperature
    (d) None above
12. At the surface level
    (a) Equatorial regions are warmer than polar regions
    (b) Equatorial regions are cooler than polar regions
    (c) Equatorial regions and polar regions have the same temperature
    (d) None above

Answers

1.	(b)	2.	(b)	3.	(a)	4.	(b)
5.	(a)	6.	(b)	7.	(b)	8.	(a)
9.	(b)	10.	(b)	11.	(b)	12.	(a)