The atmosphere of our Earth, of planets of our solar system and of exoplanets

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8. Selected Atmospheric Phenomena
8.1 Thunderstorm - clouds
Lightnings and Thunder

[See also Chapter 3: pp. 71, 77, 78; pp 93 – 99]

8.1.1 Development and Structure of Thunderstorm Cells

A thunderstorm is a complex meteorological phenomena which is associated with a discharge of electrically charged air (lightnings and thunder). On average, about 1'600 thunderstorms exist simultaneously on the Earth which take place over an area of 0.3% of the surface of the Earth. It is estimated that there are as many as 40'000 thunderstorms occurrences during one day world-wide. For introductory remarks about thunderstorms, hails, lightnings, tornados and hurricanes s. Chapter 3, pp 71, 77, 78; and pp 93-99.

Thunderstorms can develop if a sufficiently large vertical temperature decrease is present in the atmosphere. In this case, a parcel of air becomes instable by condensation (i.e. by the formation of small water droplets) and starts to rise. This is only possible if the temperature decrease is larger than 0.65 °C per 100 meters in altitude. A rising parcel of air which is condensed out, cools down by more than 0.65 °C/100 m (saturated adiabatic ascent).

But due to the released condensation heat, the parcel of air cools down less rapidly than the ambient air. For this reason it becomes warmer and due to the associated decrease of density it becomes lighter than the ambient air: a lift is generated. For the formation of a lightning, the existence of a humid air layer near the ground is necessary. The latent heat of this humid air layer is the energy supplier for moisture convection. This is the basic necessary condition for the formation of a thunderstorm. The latent heat is the hidden energy contained in the water vapour, and this energy is released as heat during the process of condensation.
Processes of development of a Thunderstorm cloud

A rising parcel of air will initially cool down (1.0 °C/100 m) until its dew point temperature is reached. At and below this temperature, the water vapour contained in the parcel of air starts to condense and a Cumulus cloud is formed. Under appropriate conditions, this Cumulus cloud can increase and grow by forming a thunderstorm cloud, a so-called Cumulonimbus cloud. At the condensation point, the energy stored in the water vapour is released in the form of thermal energy giving rise to a temperature increase. This causes a decrease of the density of the parcel of air relative to the ambient air and leads to an additional buoyancy. In the presence of a so-called conditionally unstable stratification, the parcel of air rises up to an altitude where the difference of temperature per unit height (the temperature gradient) decreases again. This causes again a decrease of the temperature- and density differences relative to the ambient air. If the density of the parcel of air is equal to the density of the ambient air, the buoyancy force disappears and the buoyancy of the air is stopped.

Usually, the equilibrium level is located in the vicinity of the Tropopause (Chapter 1, pp 7 and 9). In Central Europe, the altitude of the Tropopause is between 8 km in winter and 12 km in summer. In the Tropics, the Tropopause is at about 16 km.

Because of their inertia, the parcels of air can overshoot the equilibrium level. Such «overshooting tops» can reach altitudes up to 20 km. [see also picture in Chapter 3, p. 71].

Convection currents in Heat- and Cold front Thunderstorms

Basically, there are two kinds of thunderstorms: The air-mass thunderstorm such as the heat thunderstorm, and the multicell storm such as the cold front thunderstorm. The characteristics of these two types of thunderstorms are discussed below.

In Middle Europe, heat thunderstorms occur almost exclusively in the summer half-year. The strong solar radiation heats up the air (lower red arrows) and much water vapor is leaving the ground (evapotranspiration). The temperature is increasing strongly, mainly near the ground, while in larger altitudes it essentially remains constant. At a certain temperature (trigger temperature), warm air bubbles start to rise into the altitude, since these air bubbles are warmer and lighter than the air in their surroundings. With increasing altitude, the air bubbles are cooling down and finally, they reach the condensation level. If the atmospheric levels above are humid and unstable, thermal thunderstorms are formed. Heat thunderstorms are most common in the afternoon or in the early evening hours.

The cold front thunderstorm is initiated by the contact of humid air with a cold air front. The effect is similar to that of the heat thunderstorm as shown in the Figure at left. If a cold front is formed, the cold air is sliding similar to a wedge below the moist warm air so that the latter is lifted. In a certain altitude, the gaseous water vapour is condensed and Cumulus clouds are formed. At suitable conditions, these Cumulus clouds can grow and create thunderstorm clouds.
8.1.2 Formation of electrical charges in a Thunderstorm cloud

In nature a lightning is a spark discharge between a cloud and the ground (cloud-to-ground discharge), within a cloud (intra-cloud), between two clouds (cloud-to-cloud discharge) or from the ground to a cloud (upward lightning) (s. p. 340). As a rule, a lightning is generated during a thunderstorm caused by electrostatic charges of the cloud generated by water droplets or by raindrops. It is accompanied by thunder and it belongs to the so-called «electro-meteors». In this process, electrical charges (electrons or gaseous ions) are separated, i.e. electrical currents are flowing. Most often, lightnings are observed in the presence of Cumulonimbus clouds (s. p. 337 and picture below; in addition, see also the Figure at p. 77, Chapter 3).

The mechanism of charge separation within a cloud is not really understood. One theory assumes that the friction between snow crystals generates a charge separation. Another theory advocates that falling water droplets are electrically charged. In a third theory it is supposed that during their fall and the associated deformation, larger raindrops are ruptured and that the larger fragments acquire a positive, the smaller a negative charge («water fall electricity»). This latter mechanism could be mainly responsible for the lower part of the thunderstorm cloud. A further theory is associated with the freezing process: Here, it is postulated that during the freezing of water droplets, positively charged hydrogen ions H⁺ (protons) together with the ice crust are fragmented. In all theories, charges are separated and by means of ascending and descending winds are carried along; in this way, a large electrical field is established.

The discharge of lightning occurs if the charge separation is sufficiently large so that the breakdown potential is reached. In practical situations, this breakdown potential is substantially smaller than 1 MV/m.

Cloud-to-ground discharge between a cumulonimbus cloud and the ground

The Anatomy or Types of Lightnings

a) Cloud-to-Ground Lightning: CG
b) Cloud-to-Cloud Lightning: CC
c) Intra-Cloud Lightning: IC
d) Ground-to-Cloud Lightning: GC
**Stepped Leader, Upward connecting Leader and Return Leader**

The lightning discharge is proceeded by a series of predischarges which are directed against the ground. Thereby, a charge channel, the so-called «Stepped Leader» (SL) is generated (Figure a). This stepped leader is formed by impact ionisation of the air molecules, i.e. by «Runaway-electrons». The ionized lightning channel is formed step by step (hence, it is known as the step leader) until it has nearly reached the ground. Although the predischarges, also known as «dart leaders» are directed towards the ground, their directions are slightly changed within some meters and they can split off sporadically. This gives rise to their zigzag form and for their branching.

Shortly before the dart leaders have reached the ground, one or more faint upward «Connecting Leaders» (CL) start from the ground (Figure b). An upward connecting leader usually occurs at pointed objects (trees, masts, church towers). In most cases, one of the stepped leaders coincides with an upward connecting discharge thereby forming a closed charge channel, the so-called «Return Stroke» (RS), between cloud and ground (Figure c). The «Return Stroke» (or main lightning) has a maximum diameter of 12 mm. This is the principle lightning discharge, which is very bright and is the observed lightning. The intense radiation is caused by the formation of a plasma.

![Diagram of lightning types](image)

a) Stepped Leader (SL) \(v_{SL} \approx 300 \text{ km/s}\)

b) Upward Connecting Leader (CL) \(v_{CL} \approx 100'000 \text{ km/s}\)

c) Return Stroke (RS) \(v_{RS} \approx 100'000 \text{ km/s}\)

**Properties of Lightnings**

Temperature: The highest yet measured temperature of a lightning is about 30'000 °C (!) and has been observed in a lightning channel for a period of about one micro second (\(10^{-6}\) s). This temperature exceeds the temperature at the surface of the Sun by more than a factor of four!

Diameter: The visible diameter of a lightning is several centimeters to about 10 centimeters but an exact determination by photographic methods is very difficult.

Lengths of Lightnings: Cloud-to-ground lightnings have lengths varying between 5 and 7 km while the average length of a cloud-to-cloud lightnings is about 8 km (s. p. 340). By means of radar equipments, lengths of clouds as large as 140 km have been detected.

Velocity: The velocity \(v\) of a lightning is about one-tenth to one-third of the velocity of light \(c\) (\(c \approx 300'000 \text{ km/s}\)). Let \(v_1 \approx 30'000 \text{ km/s}\) and \(v_2 \approx 100'000 \text{ km/s}\). The circumference of the Earth is \(U = 40'000 \text{ km}\). This means that within \(\tau = 1 \text{ s}\), the lightning would travel 0.75 times and 2.5 times around the Earth, respectively.

Main lightning discharge: An average lightning contains about 4 discharges, and the duration of each is about \(t = 40 \mu s\). For a voltage of \(U = 30 \text{ MV}\) the current is \(I = 20 \text{ kA}\). The electrical energy \(E\) per discharge is given by \(E = U/t\). By substituting the above values one obtains an energy \(E = 26 \text{ kWh}\) for the 4 discharges. This is an energy which is consumed by a four-person household in about 2 to 3 days. Since 1 litre of fuel contains about 10 kWh, the lightning energy of 26 kWh is equivalent to 2.6 L of fuel. A very strong lightning is able to discharge about 10 times this energy (\(\approx 260 \text{ kWh} \rightarrow \approx 26 \text{ L fuel}\) [s. also p. 96, Chapter 3].

Light emission: The extremely high temperatures and electric fields in a lightning channel ionizes the air (oxygen and nitrogen), i.e. their electrons are pulled off and become free and mobile. In addition, the atoms are highly excited and form a plasma. As the energy of a plasma drops, the free electrons recombine and the internally excited electrons relax to their ground state. The transition of the electrons to lower states causes the emission of photons or radiation – ultraviolet – visible or infrared light which propagates with the velocity \(c\). This explains the yellow-light colour of lightning channels.
8.1.3 Development and Properties of Thunder

Thunder is caused by a sudden expansion of air, which is due to the sudden increase of temperature associated with the passage of a lightning (25'000 to 30'000 °C, s. p. 342). This process starts only in the case of an adequate supply of atmospheric humidity. The air expands with a velocity \( u \) which is larger than the speed \( v \) of sound by breaking the sound barrier: \( u > v = 340 \text{ m/s} \). A pressure wave of condensed air molecules is generated. The very hot air plasma around the lightning channel (a few meters) generates the shock wave and the lightning bang.

The intensity of a lightning bang decreases with increasing distance since the energy of the pressure wave is spread over larger areas. The bang is perceptible by the sense only in close vicinity of the lightning (about 5 km). At larger distances, a permanent murmer or rolling sound without peak clipping is perceptible. This “stretching” of the pressure wave is due to dispersion, i.e. to the fact that the lightning bang is composed of a large number of waves with different frequencies and different speeds. In addition, reflection and refraction of the sound waves as well as winds present in the traversed air play an important role. For all these reasons, the pressure wave reaches the observer at different times. If the distance between observer and lightning is too large, the thunder can not be detected acoustically and only a heat lightning can be observed.

In the absence of all the complications mentioned above, the distance between the observer and the lightning can be evaluated in a simple way: Let \( t \) be the time in seconds, which elapses between the observation of the lightning and the perception of the bang. The distance \( d \) between the lightning and the observer is then simply given by \( d = v \cdot t \). As an example we assume that \( t = 10 \text{ s} \); then the distance is given by \( d = 340 \text{ m/s} \cdot 10 \text{ s} = 3'400 \text{ m} = 3.4 \text{ km} \).

Zeus, the Greek God of heaven and thunder

Acoustic emissions of Lightnings

In the case of a Cloud-to-Ground lightning (CG), the lightning starts from the cloud and propagates perpendicularly to the ground, (p. 340, Figure a)). In this case, the direction of the lightning is essentially perpendicular to the observer who hears a fierce bang.

If the direction of the lightning is approximately parallel to the line of sight (p. 340, Figure b)), the observer hears the well known rolling of thunder. This situation prevails in the case of a Cloud-to-Cloud lightning (CC).

In case of a combination of a CG and a CC-lightning, the observer hears both, a fierce bang as well as a rolling thunder.
8.1.4 Dangers of lightnings and lightning protection

Venezuela: Refinery burns after a lightning strike
Dead cows after a lightning strike
Venezuela: Refinery burns after a lightning strike
Bearning house after a lightning strike

Lightning protection by lightning conductors and earthing

Benjamin Franklin (1706 – 1790) is considered as the inventor of the lightning conductor. He found that electrical charges are attracted by metal tips. In April 1749 he described his observations as follows: «An iron rod being placed on the outside of a building from the highest part continued down into the moist Earth, ..., following the form of the roof or other parts of the building, will receive the lightning at its upper end, attracting it so as to prevent it's striking any other part; affording it a good conveyance into the Earth, will prevent its damaging any part of the building». As lightning protectors, he installed iron rods on the top of high towers.

A lightning rod is an earthed electrical conductor (aluminum- or copper conductor with diameters between 8 and 10 cm). In the first place, a lightning rod avoids the impact of a lightning into a protected building. The impact rather takes place into the lightning protection system. In the case of an impact, this lightning protection system represents a low-resistance current path, whereby damages of the protected building can be avoided. In order that the high currents can be conducted safely into the ground, the concrete-footing ground electrode must have a low impedance. The probability, that lightning rods attract additional lightnings is so small that it can not be statistically detected.
Lightning protection by the Faraday cage

Michael Faraday (1791 - 1867) was an eminent natural scientist and a most distinguished experimental physicists. Among other things, he is the discoverer of «Faraday's law of induction» on which the «Faraday cage» is based (s. left-hand pictures below). The external electric field $E_{12}$ of the capacitor plates 1 and 2 causes an opposit displacement of charges in the metal walls of the cage. The opposing field in the inner of the cage, $E_{34}$, cancels the external field $E_{12}$: $E_{12} + E_{34} = E = 0$.

In the ideal case of a fully enclosed Faraday cage consisting of an electrically conducting material, no mobile telephony or radio reception would be possible. In the case of a lightning, persons sitting in the interior of a closed car are in a safe place because it is relatively field-free (s. right-hand picture below). For the same reasons, airplanes are usually well protected from the dangers of lightning strikes.

8.1.5 Fractal structures of lightnings and electric discharges

The word fractal is derived from Latin and stands for fractured (in medicine, a similar word is known: fracture). Fractal structures are characterized by a high degree of self-similarity. This is, for example the case, if an object consists of several small copies of itself. Thereby, the self-similarity must not be complete, i.e. substantial deviations are tolerated: it is only necessary that the smaller structures have similarities with the larger structures.

The left-hand image shows the fractal structure of a cloud-to-ground lightning. The right-hand structure illustrates impressively artificially produced discharges.
8.1.6 Ball Lightnings - Observations

This form of lightning is observed very rarely. It has the appearance of a slowly moving sphere. The diameters are usually in the range between 20 to 40 cm. It has been claimed recently that a ball lightning has been captured on video for the first time.

Not only famous people such as the Roman philosopher Seneca, Pliny the Elder, Charlemagne or Henry II of England, and in more recent times Nobel Prize winners of physics, Niels Bohr and Piotr Kapitza claim to have observed the phenomena. Also many less famous people are reporting unexpected encounters with ball lightnings. In Internet, more than a million of reports can be found (such as the ball lightning of Neuruppin in Brandenburg, Germany). On the other hand, this atmospheric phenomenon is very rare, and so far the subject is still controversial.

According to reports of eyewitnesses, ball lightnings can have different colours, including blue, yellow, pink and orange. These lightning spheres occur usually immediately after a thunderstorm.

The duration of a ball lightning can vary from some seconds to one minute, but usually they do not cause damages. A characteristic feature is the mobility of the balls: within 2 to 8 seconds, at the maximum after 30 seconds, they often change their direction; obviously, they are not carried by the wind but rather orient themselves by visible objects. They also can penetrate solid obstacles without deformations and without leaving any traces and the rain can penetrate the ball lightnings unaffected. Many witnesses also report about the appearance of spark discharges or about a loud bang at the end of their existence. It is claimed that the latter phenomenon can also cause injuries and damages.

Scientifically, the existence of ball lightnings is controversial. Despite many efforts, no mechanism has been found which is able to unify all observations. But the lack of an understanding is no counterproof. Effectively, the existence of ball lightnings is increasingly accepted.

Ball Lightning Experiments

Scientists of the Max-Planck Institute for Plasma Physics (IPP) in Garching near Munich and of the Humboldt University in Berlin (HUB) have produced plasma balls which are similar to ball lightnings. By producing an underwater discharge, luminous plasma balls have been generated at the surface of the water. The lifetime of these plasma balls is nearly a half-second and the diameters are 10 to 20 cm.

In parallel with these experiments, a research group in St. Petersburg was able to produce ball-shaped light sources which are distinctly more similar to the natural ball lightnings. These experiments strongly suggest that during the birth of ball lightnings, thunderstorm lightnings and water must act together.

The experimental set-up for producing ball-shaped light sources is rather simple: A capacitor battery \(U = 5 \text{kV}, C = 0.5 \text{mF}\) provides the energy supply. In a beaker filled with salt-water there are two electrodes where one of the electrodes is electrically isolated from the surrounding water by a clay tube. If a high voltage is applied, a current up to 60 A is flowing through the water. By an electric flashover, this current is flowing from the water into the clay tube whereby the water contained in the clay tube evaporates. After the current puls, a luminous plasmoid consisting of ionized water molecules \((\text{H}_2\text{O}^+\text{and OH}^-\text{ions})\) is produced (see upper picture).
8.2 Earth’s magnetic field, Solar wind, Magnetosphere, and Polar lights

Without the shielding of the Solar wind by the Earth’s magnetic field, no life would be possible on Earth!!

8.2.1 Internal structure of the Earth and Earth’s magnetic field

The inner Earth core extends from 5'100 km to 6'371 km below the surface of the Earth. [The average radius of the Earth is \( <R> = 6371 \) km]. Presumably, it consists on a solid nickel-iron alloy. The Outer Earth Core is located in a depth between 2'900 km and about 5'100 km below the surface of the Earth. This part of the core is a liquid nickel-iron alloy and its temperature varies between 3'000 °C and about 5'000 °C. The magnetic field of the Earth is generated by the electrically conducting iron melt in the outer core which is set in motion by the rotation of the Earth.

The magnetic field is very weak (0.2 bis 0.7 Gauss). It is also subjected to short- and long-term variations. The notion «Magnetism of the Earth», refers to the magnetic field in the close vicinity of the Earth and in the absence of external perturbations by the solar wind (undisturbed magnetic field). In a first approximation it is the field of a magnetic dipole. This field strongly decreases with increasing distance from the Earth but it extends far into the space. This space region is also called magnetosphere and is strongly disturbed by the solar wind (pp 353-356). As to the generation of the magnetic field (geodynamo) as well as to its possible pole reversal see the discussion given in Appendices 8-A-2-1 and 8-A-2-2.

[For comparison, the magnetic field of a small bar magnet in a distance of 20 cm is about 0.1 Gauss].
8.2.2 Solar wind and Magnetosphere - 1

The solar wind is a particle stream emanating from the surface of the Sun in all directions.

The solar wind is composed of high-energy charged particles, namely on protons and electrons as well as on alpha-particles (He²⁺ ions consisting of two protons and two neutrons); other particles such as atoms and non-ionized (electrically neutral) atoms are essentially absent; for this reason, the solar wind is a so-called Plasma.

In the proximity of the Earth, the solar wind has a density of about 5*10⁶ particles per cubic meters. Its velocity is very large, about 300 to 700 km/s! The Sun loses about one million tons of its mass per second (the mass of the Sun is about 1.99*10²⁷ tons). Without the shielding of the solar wind by the Earth’s magnetic field, no life would be possible on Earth !! (s. Ref. R.8.2.4, e)).

Shielding of the solar wind by the magnetic field of the Earth (Figure not to scale)

8.2.2 Solar wind and Magnetosphere - 2

Since the solar wind is a plasma, it deforms both, the magnetic field of the Sun as well as that of the Earth (s. Figure below). The terrestrial magnetic field screens the Earth to a large part from the dangerous particle shower of the Sun. Only in the case of an intensive solar wind, its particles can penetrate into the high layers of the Earth’s atmosphere. By penetration into the plasma sheet, they can produce the so-called polar lights or aurora polaris (pp 358-361). Strong polar winds can also perturb the High Frequency radio (HF radio) (s. Section 8.3).

Deformation of the terrestrial magnetic field by the Solar wind
If the solar wind propagates through the space towards the Earth, it encounters an obstacle, namely the huge magnetic field of the Earth (s. pp 353, 354). This charged particle stream approaching the Earth compresses the magnetic field of the Earth on the Sun-facing side and expands it on the opposite side where it forms a long tail (pp 353-356 and picture below). In this way, the Magnetosphere of the Earth is formed.

The boundary or outer edge of the elongated cometary body facing the interplanetary space, is a mantle having a depth of about 100 km which is called the Magnetopause (s. p. 354). Due to its high kinetic pressure, the solar wind compresses the Magnetosphere at the dayside to a distance of about 6,10^4 km from the Earth, while at the nightside, the magnetic field is elongated to a tail having a length of about 6,10^6 km (s. p. 354, 356 and picture below).

At the sun-facing side, the solar wind exhibits a transition from a supersonic to a subsonic flow, which causes a shock wave or a so-called bow shock wave. The distance between this bow shock wave and the magnetopause is about 18,000 km. Due to the strong retardation of the solar wind within the bow shock wave, the solar wind exhibits a so-called thermalization. i.e. a conversion of a large part of its kinetic energy into thermal energy; this thermalization heats up the solar wind.

During the collision of the particles of the solar wind with the Magnetopause, a separation between the protons and the electrons takes place; this is due to the so-called Lorentz force: As observed from the Earth, the protons (p) are deflected to the right while the electrons (e) are deflected to the left. Due to this separation, a positive pole is formed at the dayside (D) and a negative pole at the nightside (N). In this conducting plasma of the magnetosphere, an electrical current can flow between these two poles.

Here we show a complementary picture to that of p. 354. In addition to the deformation of the magnetic field by the solar wind, the picture shows also the electrons penetrating into the atmosphere in the surroundings of the North Pole (blue Section at upper right side). This Section shows schematically how the electrons are moving around the magnetic field lines and penetrate into the atmosphere of the Earth. By chemical reactions with oxygen and nitrogen of the air, they are generating the polar lights (pp 356 – 361).

According to the older perceptions, it is assumed that the charged particles are predominantly generated by the solar wind and the cosmic radiation. However, more recent investigations have shown that the particles originate mainly in the so-called Van-Allen belt itself (see p. 357).
Van Allen radiation belt

A Van Allen radiation belt (named after James Van Allen) is one of at least two layers of energetic charged particles (plasma) that is held in place around the planet's magnetic field (see Figure below). So far it has been assumed that these particles originate predominantly from the solar wind and from cosmic radiation (see p. 365). Newer investigations from the orbiters «Van-Allen A» and «Van-Allen B» have shown, however, that the predominant portion of the particles originate in the belts themselves: In these belts, the atoms are effectively ruptured by very strong electromagnetic fields whereby electrons and protons are liberated.

The belt essentially consist of two radiation zones: The inner radiation belt extends over low latitudes in an altitude range between 700 to 6’000 km above the Earth’s surface and it contains mainly high-energy protons (p). The outer radiation belt is located in an altitude between 15’000 to 25’000 km and contains mainly electrons (e).

Importance for Space Flights: Depending on the spatially and temporally regions, the intensity of the radiation within the Van_A llen belts can potentially be dangerous to health. For this reason, the aspect of radiation protection for manned space missions in the Earth’s orbit can not be neglected.

8.2.3 Formation of Polar Lights

Since the electromagnetic processes of the formation of polar lights are complicated, we confine ourselves to a qualitative description.

The Polar lights known as «Northern lights» at the North Pole, scientifically denoted as «Aurora borealis», and the Southern Lights «Aurora australis»), are luminous phenomena (more precisely «Electrometeors»). They are generated by the impact of charged particles of the solar wind (pp 353 – 355) into the Earth’s atmosphere of the polar regions. The Photo below shows a Polar light in Northern Norway (Reference R.8.2.7 c)).

The particles of the solar wind (electrons and protons) have an average velocity of 500 to 830 km/s (up to about 3 millions km/h) and their density is about 5 millions of particles per m³. The particles of the solar wind are directed by the magnetic field towards the magnetic Poles (pp 354, 356). In the vicinity of the magnetic Poles, the direction of the magnetic field is practically perpendicular to the surface of the Earth and therefore, the particles can penetrate into the Earth’s atmosphere (yellow arrows in the plasma sheet of the Figure at p. 354). In the atmosphere above the poles of the Earth, the particles of the solar wind are colliding with the gas molecules of the Earth (O₂ and N₂) thereby exciting the air molecules to glow (partially via complex reaction chains). These reactions take place in an altitude between 100 and 300 km above the surface of the Earth; these are the areas where the polar lights are generated. Concerning the formation of the different colours see Appendix 8-A-2-4.
1) Polar lights: «Corona» in full glory

A Corona (not to be confused with the Sun-Corona) is a form of a polar light which can be seen by an observer located exactly in the Zenith. The different rays of the Corona seem to converge in a centre.

2) Polar lights: «Bows»

For quiet conditions, i.e. in the absence of intensive streams of the solar wind, it is possible to observe the so-called «quiet bow». It extends in the east-west direction over the sky and can remain at a fixed position for more than 10 minutes.

3) Polar lights: «Bands»

If there are perturbations in the solar wind, the «quiet» bow is deformed. In this case, bumps and folds can be formed. This is referred to as «bands», because this phenomenon resembles luminous rows flowing above the sky. The bands are rapidly changing their colour, form and brightness.

4) Polar lights: «Curtains»

«Curtains» are flimsy and hazy Polar lights which extend up to several 100 km into the sky. It is often possible that the light of stars is able to penetrate the Curtains (not observed in the present Foto).
Polar lights: Types and Colours - 3

a) Aurora over Otertind (Norway)
b) Northern light in Canada
c) Polar light in Iceland
d) Polar light near Munich
8.3 The Kennelly–Heaviside Layer and High frequency Radio

8.3.1 The Ionosphere and the Kennelly–Heaviside Layer

The Ionosphere is a part of the Thermolayer. It contains a large concentration of ions and free electrons (s. Figure). It starts above the Mesosphere at an altitude of about 100 km and extends finally into the interplanetary space (s. Chap. 1, pp 7, 9; Chapter 2, pp 35, 44).

The Ionosphere originates by absorption of ionizing solar radiation, mainly by energy-rich electromagnetic waves (UV- and X-ray radiation) but also by particle radiation, mainly by electrons and protons (p. 354).

The practical importance of the Ionosphere of the Earth is associated with the world-wide radio communication: The Ionosphere reflects short-waves and thereby it enables global connections; in addition, their free electrons and ions are damping the propagation of radio waves with increasing wavelengths.

The Figure also illustrates the E-Layer, the so-called Kennelly-Heaviside-Layer of the Ionosphere. It is located at an altitude between 110 and 130 km. This is of great practical importance for the global radio communication because the E-layer reflects short-waves (s. p. 364).
8.3.2 Kennelly-Heaviside – Layer and Short-wave Transmitter

Arthur Edwin Kennelly (1861 – 1939) and Oliver Heaviside (1850 – 1925) have discovered the so-called Kennelly-Heaviside-Layer, which is also denoted as E-Layer. At 1902 the E-Layer has been discovered indepently by the two scientists. In addition, there exists also the prominent F-Layer (s. pp 363 and 365). At this page, we consider only the reflexion of waves at the E-Layer.

Radio waves in the short-wave band having frequencies between 3 MHz to 30 MHz, i.e. in the wavelength region between 100 m to 10 m are reflected at the E-Layer. After multiple reflections on the soil, they can cover long distances around the Earth. [If f is the frequency in Hz = 1/s and λ the wavelength in m, then λ = c/f, where c = 3*10^8 m/s is the velocity of light].

Reflection of short-waves at the E- and F- Layers

The Figure at p. 363 shows that a maximum of the E-Layer is present at about 120 km and that the maximum electron density is about 6*10^4 electrons per cm^3. The F-Layer has its maximum at about 300 km where the electron density is about 10^6 electrons per cm^3. The refractive indices in the Tropo-, Strato- and Mesospheres (p. 363) are practically 1, n = 1. Due to the comparatively high electric conductivity in the E- and F-Layers (caused by the quasi-free electrons and ions), the refractive indices n_e and n_p are smaller than 1 within these layers.

If the angle of incidence α of the short-waves is larger than the critical angle α_c, the wave is reflected at the conducting layers because n_e and n_p are smaller than 1. After a certain propagation length, the short-wave returns to the surface of the Earth. A large part of the ground absorbs the radiation very weakly, i.e. the soil has a low loss; this is particularly true for the reflection of the waves at the surface of the electric conducting sea, but also at humid soil (groundwater). For these reasons, and because of multiple reflections, short-wave signals can often propagate very long (worldwide) distances. This fact has already been used intensively in World Wars 1 and 2 for the sake of propaganda and information exchange. In World War 2, this has been used both, by the Germans (Nazi-propaganda-Minister Dr. Joseph Goebbels) as well as by the Allies.

8 – 16
8.4 Weitere Atmosphärische Phänomene

8.4.1 Der Regenbogen

Ein Regenbogen ist ein Phänomen der atmosphärischen Optik, das als kreisbogenfarbiges Lichtband mit vielen Spektralfarben in einer charakteristischen Farbreihenfolge wahrgenommen wird.

Ein Regenbogen entsteht durch das Wechselspiel annähernd kugelförmiger Wassertropfen mit dem Sonnenlicht, welches bei Ein- und Austritt aus dem Tropfen wellenlängenabhängig gebrochen und an der rückwärtigen inneren Oberfläche des Tropfens richtungsabhängig reflektiert wird.

Regenbogen: ausführliche Darstellung in «WASSER» von P. Brüesch; Ref. R.0.B, Abschnitt 7.2

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8.4.2 Halos: Origin and Appearance

A halo, also known as a nimbus, icebow or gloriole is an optical phenomenon produced by light interacting with ice crystallites suspended in the atmosphere, resulting in a wide variety of coloured or white rings, arcs and spots in the sky. Most halos are near the Sun or Moon. Among the most well known halo types are the circular halo (properly called the 22° halo), light pillars and sun dogs, but there are many more: some of them are fairly common, others extremely rare.

The ice crystals responsible for halos are typically suspended in cirrus or cirrostratus clouds (5 – 10 km) in the upper troposphere, but in cold whether they can also float near the ground, in which case they are referred to as diamond dust.

The particular shape and orientation of the crystallites is responsible for the type of halo observed. Light is refracted and reflected by the ice crystals and may split up into colours of dispersion (see left-hand Figure below). A mathematical derivation of 22° halos is given in Appendices 8-A-4-1 and 8-A-4-2.

8.4.3 St. Elmo’s fire: General and History

St. Elmo’s fire (also St. Elmo’s light) is a rare weather phenomenon in which luminous plasma is created by a corona discharge from a sharp or pointed object in a strong electric field in the atmosphere.

St. Elmo’s fire is named after St. Erasmus of Formiae (also called St. Elmo, one of the Italien names for St. Erasmus, the other being St. Errasmo), the patron saint of sailors. The phenomenon sometimes appeared on ships at sea during thunderstorms and was regarded by sailors with religious awe for its glowing ball of light, accounting for the name (right-hand picture). Elmo or Erasmus (left-hand picture) was born in the Roman city Formiae in Campagna, Southern Italy under the rule of the Roman Emperor Diocletian. Elmo became a bishop of Formiae and converted to Christianity. He was subsequently arrested, terribly tortured and finally he was beheaded.
St. Elmo’s Fire is a plasma. A normal gas is composed of molecules (air is composed of oxygen-\((O_2)\) and nitrogen molecules \((N_2)\)). The electric field around the objects in question causes ionization of the air molecules producing a faint glow easily visible in low-light conditions. Roughly, 1'000 volts per centimeter induces St. Elmo’s fire; the voltage depends greatly on the geometry of the object, so discharges are more intensive at the ends of pointed objects such as lightning rods, masts, spires and chimneys, and on aircraft wings. St. Elmo’s fire can even appear on leaves, grass, and even of cattle horns. Often accompanying the glow is a distinct hissing sound. It is sometimes confused with ball lightning (s. pp 349, 350).

Conditions that can generate St. Elmo’s fire are present during or after thunderstorms, when high voltage differentials are present between clouds and ground. The nitrogen and oxygen in the Earth’s atmosphere cause St. Elmo’s fire to fluoresce with blue or violet light (see Figure below).

![St. Elmo’s fire observed from an airplane](image)

**8.4.4 Purple light at twilight**

The purple light is a twilight phenomenon, causing a purple colour before sunrise or after sunset. It starts about 15 minutes after sunset at the western horizon if the sun is about 2° below the horizon. It is due to scattering and reflection of light at small dust particles and dust in the atmosphere. During twilight, the angle of light incidence is very favorable, because no direct Sunlight is present and scattered. Therefore, the light scattered by dust particles is undisturbed by Sunlight and is directly visible.

The appearance, the visibility and the intensity of purple light are strongly dependent on weather and on the observation conditions; it also depends on the air pressure and the wind conditions in both, the stratosphere and troposphere. For the occurrence of purple light, there are several origins such as forest fires, volcanic eruptions and atmospheric pollution.

The purple light is caused by the superposition of both, the scattered red light of the lower hazy layers as well as of the scattered blue light of the higher layers of the atmosphere. By Rayleigh scattering (s. Ref. R.8.4.5 e)) of the white Sunlight at the air molecules, the blue spectral contributions are observed. The hazy particles in the lower layers are causing Mie-scattering (s. Ref. R.8.4.5 g)).

![The purple light is a twilight phenomenon](image)

Purple and violet are similar, though purple is closer to red. In optics, there is an important difference; purple is a composite color made by combining red and blue, while violet is a spectral color, with its own wavelengths \(\lambda\) on the visible spectrum of light: \(400\ \text{nm} < \lambda < 450\ \text{nm}\).
8.4.5 Airglow or Nightglow

Airglow (also called nightglow) is the very weak emission of light by a planetary atmosphere. In the case of the Earth’s atmosphere, this optical phenomenon causes the night sky never to be completely dark, even after the effects of straylight and diffused sunlight from the far side are removed.

The Airglow phenomenon was first identified in 1868 by the Swedish scientist Ångström. It is caused by various processes in the upper atmosphere, such as the recombination of atoms, which are photoionized by the sun during the day, luminescence caused by cosmic rays striking the upper atmosphere and chemiluminescence caused mainly by oxygen and nitrogen reacting with hydroxyl ions at heights of a few hundred kilometers. It is not noticeable during daytime because of the scattered light by the sun. The airglow at night may be bright enough to be noticed by an observer and is generally bluish in colour.

One airglow mechanism is when an atom of nitrogen combines with an atom of oxygen to form a molecule of nitric oxide (NO). In the process, a photon is emitted. This photon may have any of several different wavelengths characteristic of nitric oxide molecules. The free atoms are available for this process, because molecules of nitrogen (N₂) and oxygen (O₂) are dissociated by solar energy in the upper reaches of the atmosphere and may encounter each other to form NO.

Red Sprites, Blue Jets and Elves are all related to strong lightnings

Red Sprites are very brief, luminous glows that occur in the middle atmosphere. Sprites often start at a height of about 72 km and extend upwards to the edge of the Ionosphere. The portion of the event that might be visible to the naked eye often lasts less than one hundredth of a second. Sprites are caused by lightnings. They result from extremely powerful discharges, sometimes occurring with thunderstorms. They are almost always triggered by a powerful positive cloud-to-ground (CG) flash (s. pp 339, 340) which lowers massive amounts of electrical charge to the Earth. It is believed that sprites result when the electrons in the thin atmosphere are accelerated by the sudden change in electric field strength. When the electrons slam into molecules of nitrogen, they cause the nitrogen to glow. Certain energies result in primarily red optical emissions, hence the red colour of sprites.

Blue Jets appear to spurt upwards from cloud tops at speeds of about 80 to 160 km per second, reaching heights of up to 40 km before fading. They last generally less than a quarter of a second, but it is possible to perceive their upward motion with the unaided eye. They are generated by storms with high lightning rates. They do not appear to be related to specific cloud-to-ground lightning discharges.

Elves result from an especially powerful electromagnetic radiation pulse that emanates from certain lightning discharges. As the energy passes upwards through the base of the Ionosphere, it causes the gases to briefly glow. Though as brite as a sprite, the elf only lasts for less than a thousandth of a second. They are most likely red in colour and look like giant expanding doughnuts. They occur at heights between 96 to 105 km.
Appendix: Chapter 8

**Earth’s magnetic field: Magnetic and geographical Poles**

a) Cross-section through Earth

- **Crust**
  - 0-100 km thick

- **Outer core**
  - 2900km - 5100km deep

- **Inner core**
  - 5100km to 6378km deep

- **Lithosphere**
  - Crust and uppermost Mantle

- **Mantle**
  - 100km - 2900km deep

- **Core**
  - 6378 km

b) Earth’s magnetic field

Earth’s magnetic field that extends from the Earth’s inner core to where it meets the solar wind (s. pp 353 – 356). The above picture is a Computer simulation of the Earth’s magnetic field in a period of normal polarity (s. pp 8-A-2-2, 8-A-2-3). The lines represent magnetic field lines, blue when the field points towards the center and yellow when away. The rotation axis of the Earth’s is centered and vertical. The dense cluster of lines are within the Earth’s core.

**Liquid outer core:** 2’900 – 5’100 km

- **Temperature:** 3’700 – 4’600 °C; **Density:** 12.1 g/cm³
- **Pressure:** 1’500 – 3’400 kbar

**Solid inner core:** 5’100 – 6’378 km

- **Temperature:** 4’600 – 6’000 °C; **Density:** 12.5 g/cm³
- **Pressure:** 3’400 – 3’600 kbar

[3’600 kbar = 3.6 Million bar]
Decrease of the magnetic field and Pole reversal - 1

On the basis of the reconstruction of the paleomagnetic field and the magma of the oceanic crust, it is known that the Earth’s magnetic field is reversed about every 250,000 years. The last time this happened is, however, about 780,000 years ago. The magnetic pole jump, i.e. the magnetic field reversal, took about 4,000 to 10,000 years (Computer simulations suggest about 9,000 years).

Since the magnetic field is decreasing, it is possible that in the not too distant future a pole reversal could take place (estimates: in the years between 3,000 to 4,000); This conjecture is, however, not scientifically validated. In general, it should be noted, that within the last 120 million years, the frequency of such pole reversals has increased.

There are some indications for an imminent polar reversal: There are certain locations in the core-mantle zone in which the direction of the magnetic field has reversed its direction with respect to that common for this hemisphere. These regions are measurably increasing and are moving on and on continuously. Based on this phenomenon, the decrease and subsequent reversal of the dipole moment can be explained. The Figure on the left shows that the dipole moment m has decreased by 6.4% between 1,900 und 2,000. In the year 2014, m was about 7.72 *10^{22} Am². Geological investigations of ceramic specimens have shown that within the last 4,000 years, m has decreased by about 50%.

Decrease of the magnetic dipole moment in the last 100 years.

8-A-2-2

Decrease of the magnetic field and Pole reversal - 2

During the phase of pole reversal, the Earth would be more strongly exposed to the solar wind (pp 353-355; p. 8-A-1-1). This corresponds to the observation that in the respective sediment layers a species turnover has been detected. It is possible that the oscillation of the Earth’s magnetic field and the associated DNA mutation caused by high-energy radiation was a pacemaker and at the same time a significant impetus of the evolution. Moreover, it can be assumed that due to the interaction of the ions of the solar wind in the ionosphere, magnetic flux lines are created which are leading from the sun-facing side to the opposite side of the Earth. This self-magnetization creates a magnetic screening of the Earth from the solar wind and has a similar protecting effect to live on Earth as the present magnetic field.

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Simulation of the Earth’s magnetic field. The simplified dipole approximation is only valid in the immediate outside area of the Earth.

Chaotic perturbation of the Earth’s magnetic field. The field in larger distances from the Earth is quite different from a dipole field.

The magnetic field of the Sun reverses much more rapidly its direction, about every 11 years. During the reversals it does not, however, vanish completely, but it becomes more chaotic.

8-A-2-3
The colours of Polar lights

The origin of the different colours of polar lights is relatively complex. As a supplement to p. 358 we content ourselves with a qualitative discussion.

The solar wind particles from the magnetosphere penetrating into the atmosphere are colliding with the oxygen- and nitrogen atoms or molecules of the air. Thereby, the latter are excited, i.e. as a result of the collision, an electron of an air particle is excited to a higher quantum state. As a result of relaxation of the electrons into the ground state, the absorbed energy is emitted in the form of light.

Polar lights are thus generated if electrical charged particles of the solar wind collide with oxygen- or nitrogen atoms or molecules in the upper layers of the atmosphere and cause ionization. The colour of the emitted light depends on the species of the excited atoms or molecules. Oxygen emits green and red light, whereas nitrogen emits blue and violet light. Since the light emitted by oxygen is particularly intensive, polar lights often show a green colouring. Thereby, the green light is most intensive at an altitude between 120 and 140 km while the red light is most intensive at an altitude above 200 km.

Depending on the actually prevailing circumstances, one or more ground colours or combination colours can be observed. The Fotos depicted at pp 358 – 361 and the present Foto give an impression of the variety and beauty of the resulting colours produced by the polar lights.

Some Birds can sense the magnetic field of the Earth

Some birds can sense the Earth’s magnetic field and orient themselves with the ease of a compass needle. This ability is a massive boon for migrating birds, keeping frequent flyers on the straight and narrow. But this incredible sense is closely tied to a more mundane one – vision. Thanks to special molecules in their retina, birds like the European robins (see picture) can literally see magnetic fields. The fields appear as patterns of light and shade, or even colour, superimposed onto what they normally see. Katrin Stapput from the Goethe University in Frankfurt has shown that this “Magneto-reception” ability depends on a clear image from the right eye.
Halo: Refraction of Light at a hexagonal Ice crystal - 1

The Figure below shows the refraction of a light beam of the Sun at a hexagonal ice crystal (s. p. 368) (the triangle ABC has been added for didactical reasons). The angle $\gamma$ is $60^\circ$. In the Figure it has been assumed that the (red) lightbeam (parallel to the side AB) impinges horizontally on the crystal and is refracted the first time at the point $P_1$. After traversing the crystal, the beam is refracted a second time at the point $P_2$.

$\alpha$: angle of incidence  
$\beta_1$: refractive angle at point $P_1$  
$\beta_2$: refractive angle at point $P_2$  
$\alpha_c$: refractive angle after exit at $P_2$  
$\delta$: angle of deflection:

Refractive indices:

$n_1 = 1$ (Air); $n_2 = n = 1.310$ (Ice $^*$)

$\delta = (\alpha_1 + \alpha_2) - (\beta_1 + \beta_2)$  
$\beta_1 + \beta_2 = \gamma$  
$\rightarrow \delta = \alpha_1 + \alpha_2 - \gamma$ (1)

Law of refractions:

\[ \sin(\alpha_i) = n \sin(\beta_1) \]  
\[ n \sin(\beta_2) = \sin(\alpha_c) \]  
\[ n \sin(\beta_2) = \sin(\alpha_c) \] (4)

Halo: Refraction of Light at a hexagonal Ice crystal - 2

Based on the equations (1) to (4) of p. 8-A-4-1 we calculate the angle of deflection $\delta$ as a function of $\alpha_1$, $\gamma$ and $n$: From $\sin(\gamma - \beta_1) = \sin \cos \beta_1 - \cos \sin \beta_1$ and from $\cos \beta_1 = (1 - \sin^2 \beta_1)^{1/2}$ we obtain after some rearrangements:

$\alpha_2 = \arcsin(n \sin \beta_2) = \arcsin \left[ \sin \left( n^2 - \sin^2 \alpha_1 \right)^{1/2} - \cos \sin \alpha_1 \right] \] (5)

[Definition of the arc function: if $y = \sin(x)$ then $x = \arcsin(y)$]

Substituting equation (5) into equation (2) we obtain the following relation:

$\delta(\alpha_1, \gamma, n)) = \alpha_1 - \gamma + \arcsin \left[ \sin(\gamma) (n^2 - \sin^2 \alpha_1)^{1/2} - \cos \sin \alpha_1 \right] \] (6)

It can be shown that the angle of deviation $\delta$ is minimal if $\alpha_1 = \alpha_2 = \alpha$ and $\beta_1 = \beta_2 = \beta$, i.e. for the case of a symmetrical path for which the light path from $P_1$ to $P_2$ in the Figure of p. 8-A-4-1 is parallel to AB. The minimum deviation angle is then given by

$\delta_{\min} = 2 \arcsin[n \sin(\gamma/2)] - \gamma$

For hexagonal Ice crystals, i.e. for $\gamma = 60^\circ$ and $n = 1.310$ (yellow Na-D line) it follows: $\delta_{\min} = 21.8^\circ$ and $\alpha = 40.9^\circ$. The maximum intensity of the Halo is then at $\delta_{\min}$ (s. present Figure and the Halo shown at p. 368).
Night clouds or Noctilucent clouds (NLC) are made of crystals of water ice. Noctilucent roughly means night shining in Latin. They are most commonly observed in the summer months at latitudes between 50° and 70° north and south of the equator. They can be observed only when the Sun is below the horizon. They are the highest clouds in Earth's atmosphere, located in the Mesosphere at altitudes of around 75 to 85 km (s. Chapter 2, p. 44). They are formally too faint to be seen, and are visible only when illuminated by sunlight from below the horizon while the lower layers of the atmosphere are in the Earth's shadow. NLC's are not fully understood and are a recently discovered meteorological phenomenon; there is no record of their observation before 1885. NLC's can form only under very restrictive conditions; their occurrence can be used as a sensitive guide to changes in the upper atmosphere. Clouds in the Earth's lower atmosphere form when water collects on particles (Chapter 3, Section 3.3, pp 68 – 78), but mesospheric clouds may form directly from water vapour in addition to forming on dust particles. The sources of both the dust and the water vapour in the upper atmosphere are not known with certainty.
8.1 Formation and Properties of Thunderstorms and Lightnings

R.8.1.0 p. 335: Thunderstorm clouds - Lightnings and Thunder

R.8.1.1 p. 336: 8.1.1 Development and Structure of Thunderstorm Cells
   b) Thunderstorms - Introduction - Map of Thunderstorms in the U.S. found under: Thunderstorms - Introduction (Images)
   c) Latent heat (Definition) - http://www.thefreedictionary.com/latent+heat
   d) Entstehung eines Gewitters - Nationale Plattform Naturgefahren PLANAT – Swiss confederation
      www.planat.ch/de/wissen/gewitter/entstehung-gew

R.8.1.2 p. 337: Processes of Development of a Thunderstorm Cloud
   b) Cumulonimbus_Cloud - Picture from Gabrielle De Santi and Tiffany Maenner - (Google)
   d) see also Chapter 3, p. 71

R.8.1.3 p. 338: Heat Thunderstorms and Cold front Thunderstorms
   a) References R.8.1.2 a) and R.8.1.2 c)
   b) Informationen über die Entstehung von Gewittern, Hagel und Tornados
      http://www.sturmwetter.de/texte.gewitterinfos.htm
      (Figure Texts translated from German to English by P. Brüescj)

R.8.1.4 p. 339: Formation of electrical charges in a Thunderstorm cloud
   b) Blitz - http://de.wikipedia.org/wiki/Blitz
   c) Wissen + Schulungsförderung >> Blitz und Donner – Wie entsteht er eigentlich?
      http://www.stormhunters-germany.de/167537-Blitz-und-Donner-Woe-entsteht-er-eigentlich.html
   d) see also Chapter 3, p. 77
      Letzte Aktualisierung Juli 09 2013 - suite 101.de/article/die-entstehung-von-gewittern-146220
R.8.1.5 p. 340: The Anatomy or types of lightnings
a) Cloud-to-Ground Lightning: CG
b) Cloud-to-Cloud Lightnings: CC
C) Intra-Cloud Lightning: IC
d) Ground-to-Cloud Lightning: GC

e) Wie entlädt sich ein Blitz bei einem Gewitter?
   [All pictures from Google – Images]

R.8.1.6 p. 341: Stepped Leader, Upward connecting Leader and Return Leader
a) Reference R.8.1.4 a)

b) Reference R.8.1.4 b)

   [contains picture about: The three phases of cloud-to-ground-lightning discharge]


R.8.1.7 p. 342: Properties of Lightnings
a) Lightning Part 3: The Lightning Bolt

b) Characteristics of lightning current - www.dehn.org/akt/lighning


e) Blitz und Gewitter - http://www.ping.de/schule/pg/erneuerp-wetter-blitzverh/interne.htm


Eidgenössisches Departement für Umwelt, Verkehr und Kommunikation (UVEK)
[PDF] Umrechnungsfaktoren / Facteur de conversation


R.8.1.8 p. 343: Development and Properties of Thunder

b) What causes the sound of thunder? - http://www.loc.gov/r/m/scitech/mysteries/thunder.html


R.8.1.9 p. 344: Acoustic emission of Lightnings
Environment Canada – Weather and Meteorology
The Sound of Thunder - contains three pictures of different thunders

http://ec.gc.ca/foule-th-lightning/default.asp?Fanning-En&n=4EFD3A52-1

R.8.1.10 p. 345: Dangers of lightnings and lightning protection
a) New tank burns at Venezuela refinery; death toll revised down

b) First three images from: www.Google.ch

c) Oelraffinerie in Venezuela: Speichertank steht nach Blitzzuschlag in Flammen

R.8.1.11 p. 346: Lighting protection by lightning conductors and earthing
a) Benjamin Franklin - http://wikipedia.org/wiki/Benjamin_Franklin

b) Benjamin Franklin - http://www.todayinsci.com/F/Franklin_Benjamin/FranklinBenjamin-Quotations.htm

c) Lightning rod - http://en.wikipedia.org/wiki/Lightning_rod

R.8.1.12 p. 347: Lightning protection by the Faraday cage


R-8-2

R-8-3

8 – 27
R.8.1.12 p. 348: Fraktale Eigenschaften von Blitzen


(g) Elektronik Kompendium - [http://www.elektronik-kompendium.de/sites/gerd/0205141.htm](http://www.elektronik-kompendium.de/sites/gerd/0205141.htm)

(h) Faraday cage in the field of a plate condensor

(i) Faraday – cage: Figure from [www.google.ch](http://www.google.ch) search under «Faraday – Käfig im Feld des Plattenkondensators»

(The figure has been slightly modified by P. Brüesch by adding the external field E_x and the opposite inner field E_y: E_x + E_y = E = 0, where E = 0 is the vanishing resulting field in the cage).

(k) Figure of Lightning strike on the cage of a car:- found in Internet - images: «Blitschlag auf Auto-Käfig»

R.8.1.13 p. 348: Fraktale Eigenschaften von Blitzen

(a) Fractal Dimension of Dielectric Breakdown

L. Niemeyer, L. Pietronero, and H.J. Wiesmann


(b) Fractal: [http://de.wikipedia.org/wiki/Fraktal](http://de.wikipedia.org/wiki/Fraktal)


(e) Jacket Interview - Ben Lerner - (right-hand-Figure): [http://jacketmagazine.com/2005/john-lemm.html](http://jacketmagazine.com/2005/john-lemm.html)

(f) Bild links auf p. 348: Fraktale Struktur eines Blitzen


R.8.1.14 p. 349: Ball lightnings - Existence and Observations

(a) Ball Lightning - [http://en.wikipedia.org/wiki/Ball_lightning](http://en.wikipedia.org/wiki/Ball_lightning)

(b) The Question of the Existence of Ball Lightning - Plenum Press, 1971

http://amasrj.com/tesla/ballext.bt

(c) Does ball lightning really exist?


(d) Periodically, I hear stories about ball lightnings. ... - Scientific American - July 18, 1997

https://www.scientificamerican.com/article/periodically-i-hear-stories/

(e) Scientists accidentally record ball lightning in nature for the first time - by Nick Statt – January 17, 2014


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R.8.1.15 p. 349: (cont)


(g) Arten von Blitzen – Library - [http://library.thinkquest.org/03oct/013522p_ForkedLightning.htm](http://library.thinkquest.org/03oct/013522p_ForkedLightning.htm)

(h) Kugelblitz über Neuppin - [http://www.met.fu-berlin.de/~manfred/Kugelblitz.html](http://www.met.fu-berlin.de/~manfred/Kugelblitz.html)

(i) Kugelblitz trifft deutschen Touristenbus

[http://www.t-online.de/nachrichten/panorama/id_48816992/kugelblitz-trifft-deutschen-touristenbus-.html](http://www.t-online.de/nachrichten/panorama/id_48816992/kugelblitz-trifft-deutschen-touristenbus-.html)

R.8.1.16 p. 350: Ball Lightnings - Laboratory Experiments

(a) Ball lightning - [http://www.ipp.mpg.de/977926/kugelblitze](http://www.ipp.mpg.de/977926/kugelblitze)

(b) Ball-lightning in the laboratory - [https://www.ipp.mpg.de/ipp/cms/en/presse/archiv/05_06_pi](https://www.ipp.mpg.de/ipp/cms/en/presse/archiv/05_06_pi)

(c) How to make a Stable Plasmod (Ball Lightning) with the GMR v1.0 (Graphite Microwave Tesonator)

[http://fablab.ras.in/planmesa/gmr/](http://fablab.ras.in/planmesa/gmr/)

(d) Kugelblitz im Labor IPP: Max-Planck Institut für Plasmaphysik

[http://www.ipp.mpg.de/ipp/cms/de/presse/archiv/05_06_pi.html](http://www.ipp.mpg.de/ipp/cms/de/presse/archiv/05_06_pi.html)

(e) Max-Planck Forschung - enthält Abschnitt über «Kugelblitze aus dem Wasserbecher»

Das Wissenschaftsmagazin der Max-Planck-Gesellschaft

[PDF] Plasma – Max – Plank Gesellschaft

[https://www.mpg.de/905905/MPF_2008_1.pdf](https://www.mpg.de/905905/MPF_2008_1.pdf)

(f) Im Labor erzeugte kugelblitz-ähnliche Plasmawolke

gefunden unter «Kugelblitz im Labor»: [www.google.ch](http://www.google.ch) - Bild

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R-8-4 - 8 – 28
Earth's magnetic field – Solar wind – Magnetosphere and Polar lights

R.8.2.0 p. 351: Earth's magnetic field, Solar wind, Magnetosphere and Polar lights

R.8.2.1 p. 352: Internal Structure of the Earth and Magnetic Field

a) Earth's magnetic field - [PDF] http://en.wikipedia.org/wiki/Earth's_magnetic_field

R.8.2.2 p. 353: Solar wind and magnetic field of the Earth – 1

c) Sonnenwind und Weltraumwetter - Rainer Schwenn and Kristian Schlegel

R.8.2.3 p. 354: Solar wind and magnetic field of the Earth – 2

b) Magnetsturm – Kosmos-GEO.de

Without Earth's magnetic field which protects us from the Solar wind, no life would be possible on Earth.
R.8.2.6  p.  357: Van Allen belt
a) Van Allen radiation belt
   www.en.wikipedia.org/wiki/Van_Allen_radiation_belt
b) Mystery of Earth’s radiation belts solved
   «Van Allen belts accelerate their own particles rather than trapping them» - Ron Cowen - 25 July 2013
      c) Forces on a Moving Charge in a Magnetic Field: Examples and Applications
    on pages 67 of this contribution; Short discussion with two Figures of magnetic field of the Earth
      including the «Inner and Outer Van Allen belt» - cnx.org>Contents>College Physics
d) Van Allen radiation belt

e) Van-Allen-Gürtel: Forscher lösen Geheimnis der irdischen Strahlungsringe
   SPIEGEL ONLINE – WISSENSCHAFT (26. 06. 2013)
   - Laut der neuen Theorie sind es elektrische Felder innerhalb des Gürtels, die umherwandernde Atome zerreißen und ihre Elektronen abtrennen. Diese werden bis zu 99% der Lichtgeschwindigkeit beschleunigt.
   - According to the new theory, the very strong electromagnetic fields within the belts are rupturing the atoms and produce electrons (and protons). The electrons are accelerated to about 99% of the velocity of light.

R.8.2.7  p.  358: Formation of Polar Lights
a) Aurora (Astronomy) - http://en.wikipedia.org/wiki/Aurora
http://home.online.no/~khgott/Polarlichtseite.html

d) Deutsche Physikalische Gesellschaft – Fachverband Didaktik der Physik
   Beitrag aus der Reihe: Karl-Heinz Lotze, Werner B. Schneider (Hrsg)
   Wege in der Physikdidaktik - Band 5 - Naturphänomene und Astronomie
   [PDF] Schlegel Kristian_ Polarlicht - Solstice

R.8.2.8  pp 359 – 361: Fotos of Polar lights: Forms and Colours
a) Aurora - https://en.wikipedia.org/wiki/Aurora
b) pp 359,360: Fotos found in Internet under: Polar lights – Forms and Colours
   d) p. 361: Foto c): Polarlicht in Iceland (from BLOG!)
      www.davidkoester.de/.../bild-des-monats-polarlichter-ueber-jokulsarien...
      http://www.swissinfo.ch/spa/index/Sonnenstuehme_wenden_sich_von_Erde_ab.html?cid=3602258

R.8.2.9  pp 358 – 361: Polar lights (Text)
   von Dr. Otto Braumander; Verein Antaras. NÖ Amateurastronomen
   [PDF] Polarlichter – Verein Antras
   [This article contains a very good summary of the most important aspects of Northern lights: translated from German to English by P. Brüesch]
8.3 Kennelly–Heaviside-Layer, Short-wave Transmitter - Varia

R.8.3.0 p. 362: Kennelly–Heaviside and High frequency radio - Introduction

R.8.3.1 p. 363: The Ionosphere and the Kennelly–Heaviside Layer

- Ionosphere: https://en.wikipedia.org/wiki/Ionosphere
- Kennelly – Heaviside Layer: https://en.wikipedia.org/wiki/Kennelly%E2%80%93Heaviside_layer
- Ionosphäre: http://de.wikipedia/wiki/Ionosph%C3%A4re
- Der Beginn des Kurzwellen-Rundfunks: http://www.wabweb.net/radio/radio/kw_beginn.htm

R.8.3.2 p. 364: Heaviside-Layer and Short-wave transmitter

- Oliver Heaviside: https://en.wikipedia.org/?title=Oliver_Heaviside
- Text: from References of R.8.3.1
- Figure from: www.google – pictures: Figure Text translated from German to English by P. Brüesch

R.8.3.3 p. 365: Reflection of short-waves at the E- and F- Layers

- Picture of Reflection (Propagation modes and paths) of short-waves at the E- and F- layers
- Ionospheric Wave Propagation: by Professor David Jenn, Department of Electrical and Computer Engineering / Monterey, California
- Kurzwellenrundfunk: http://de.wikipedia.org/wiki/Kurzwellenrundfunk
- L. Bergmann und C. Schafer: Lehrbuch der Experimentalphysik: Editor: De Gruyter - Band 2: Elektrolytlösleiche
- s. auch unter: books.google.ch/books?id=3111442881; p. 382

8.4 Other Atmospheric Phenomena

A detailed discussion about Rainbows can be found in «WASSER» from P. Brüesch, Chapter 7, Section 7.2, pp 327 – 339, (s. Ref. R.0.4 of this work about «The Atmosphere of our Planet»)

R.8.4.2 p. 368: Halos: Origin and Appearance

- Ice Crystal Halos: http://www.atoptics.co.uk/haosim.htm
- [enthält physikalische Grundlage für minimalen Winkel von 22°]
- 22° Degree Halo: A ring of light 22 degrees from the sun or moon
- Images from 22 degree Halo; second picture: Refraction at hexagonal single crystals
- Beautiful sun halo over Stockholm today - Photo of Sunset with Halo; Foto of Tomas Oneborg

R.8.4.3 p. 369: St. Elmo’s fire: General and History

- St. Elmo’s fire: http://en.wikipedia.org/wiki/St._Elmo’s_fire
- Elmsfeuer: http://de.wikipedia.org/wiki/Elmsfeuer
- Bild von Schiff in Not mit Elms Feuer an den Mastspitzen
- Saint Elmo: http://www.catholic-saints.info/patron-saints/saint-elmo.htm

R.8.4.4 p. 370: St. Elmo’s fire: Physical Aspects

- What causes the strange glow known as St. Elmo’s Fire?
- Is this phenomenon related to ball lightning?
  http://www.sciencedaily.com/releases/2005/06/050602083449.htm
- Was ist das Elmsfeuer? http://www.pm-magazin.de/?zt=1812418298
- What is St. Elmo’s Fire?
  http://science.howstuffworks.com/nature/climate-weather/atmosphere-elmo-fire.htm
Purple light at Sunrise and Sunset

a) Purple Light and Twilight Arch
b) Measuring and modelling twilight's purple light
c) Purple light
   - http://glossary.ametsoc.org/wiki/Purple_light
d) Purpurlicht
   - http://de.wikipedia.org/wiki/Purpurlicht
   [Text translated from German to English by P. Brüesch; contains also the Figure]
e) Rayleigh scattering
   [Rayleigh scattering is the elastic scattering of light by particles with diameters d much smaller than the wavelength \( \lambda \) of light, i.e. scattering of visible light by oxygen- and nitrogen molecules of the air. For purple light this condition is satisfied because \( \lambda \approx 400 \text{ nm} \) and \( d(O_2) = 0.121 \text{ nm} \), \( d(N_2) = 0.11 \text{ nm} \).
]
f) Rayleigh-Streuung
g) Mie scattering
   - http://en.wikipedia.org/wiki/Mie_scattering
   [Mie scattering suggests situations where the size d of the scattering particles is comparable to the wavelength \( \lambda \) of the light. A reasonable condition is \( 0.2 \lambda < d < 2 \lambda \). For \( \lambda = 400 \text{ nm} \) (purple light) the diameters of the dust particles are in the range 80 nm to 800 nm.]
h) Mie-Streuung
   - http://de.wikipedia.org/wiki/Mie_Streuung

Airglow or Nightglow

a) Airglow
b) Airglow
   - http://de.wikipedia.org/wiki/Airglow
c) Foto (left-hand-side): Astro Bob - Is there true darkness?
   - http://astrobob.areavoices.com/2009/02/25/is-there-true-darkness/
d) Foto (right-hand-side) aus: Science and Analysis Laboratory / NASA
   in: Frankfurter Allgemeine: «Globale Erkältung (in der Mesosphäre»
e) Airglow

Red Sprites, Blue Jets and Elves

a) Sprites, Blue Jets, Elves and «Superbolts»
   - http://www.sky-fire.tv/index.cgi/spritesbluejetelves.html#18
b) Red Sprites and Blue Jets
   - http://elf.alaska.edu/elf/tv/
c) Sprite (Wetterphänomene) - Text und Bild aus http://de.wikipedia.org/wiki/BlauJet
References to Appendix – Chapter 8

   a) Left-hand picture: Cross-section through Earth - from: www.google.ch
   b) Right-hand picture: Earth’s magnetic field - http://en.wikipedia.org/wiki/Earth’s_magnetic_field

   d) Reversals: Magnetic Flip - http://www.geocomag.bgs.ac.uk/education/reversals.html
   It is the opinion of the present Author, that this short summary is written very clearly,
differentiated and objectively. In addition, it also contains the Figure of p. 8-A-2:2
   (contains Texts for pp 8-A-2:2 and 8-A-2-3 - translated from German to English by P. Brüesch)
   (contains pictures for p. 8-A-2:3 / Figure Text translated from German to English by P. Brüesch)


R.A.2.3 p. 8-A-2:4 - The Colours of Polar lights

R.A.2.4 p. 8-A-2:5 - About the Mechanisms of Magnetic Orientation in Birds
   a) «Robins can literally see magnetic fields, but only if their vision is sharp» http://blogs.discovermagazine.com/notrocketscience/2010/07/08/robinscanliterallysee-magnetic-fields-but-only-if-their-vision-is-sharp/565Vu.1 er1982g

R-A-4.1 pp. 8-A-4:1 and 8-A-4:2:
   b) Prisms - http://www.hyperphysics.phy-astr.gsu.edu/hbase/prism.html
   c) The 22° Halo - http://www.hyperphysics.phy-astr.gsu.edu/hbase/.../halo22.html
   d) Lichtbrechung in der Atmosphäre - «Light refraction in the Atmosphere» - Universität Regensburg
   von Florian Albrecht zum Seminar «Phänomene der klassischen Optik» - (Sommersemester 2008)
   www.physik.uni-regensburg.de/forschung/schwarz/s1-Atmosphäre.pdf...
   e) Die Brechung des Lichtes – Chemagpedia - «The refraction of Light» - Chemagpedia
   http://www.chemagpedia.de/vsegenime/vuc/vuc/de/ph/14/eineinhuengung/geooplik/brechung/vuc/Paus/vac/der/...
   Die Arbeit enthält die grundlegenden Gleichungen zur Berechnung der Brechung am hexagonalen Eis Kristall
   [This work contains the basic equations for the evaluation of the refraction of light at a hexagonal ice-crystal] Figur des hexagonalen Eiskristalls mit Dispersionsprisma von p. 8-A-4:1 erstellt von P. Brüesch
   [Figure of hexagonal ice crystal with dispersion prism shown at p. 8-A-4:1 from P. Brüesch]
   f) Halo - [PDF] Lie, «Ein Halo ist ein heller Ring um die Sonne» - [-A Halo is a bright ring around the Sun] physik11-beispiele/Halo/Halo.pdf
   Enthält Figur des Ablenkungswinkels als Funktion des Einfallswinkels (p. 8-A-4:2)
   [Contains the Figure showing the angle of deviation as a function of the angle of incidence (p. 8-A.4:2)]

   http://earthsky.org/space/what-makes-a-halo-around-moon

R.A.4.4 p. 8-A-4:4 - Noctilucent clouds or Night clouds
   (right-hand picture: Photograph by the crew of the ISS)
   (left-hand picture)
   c) Leuchsende Nachtwolken - http://www.metopos.de/themen/nlc

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