MODULE 1

TOPIC 1

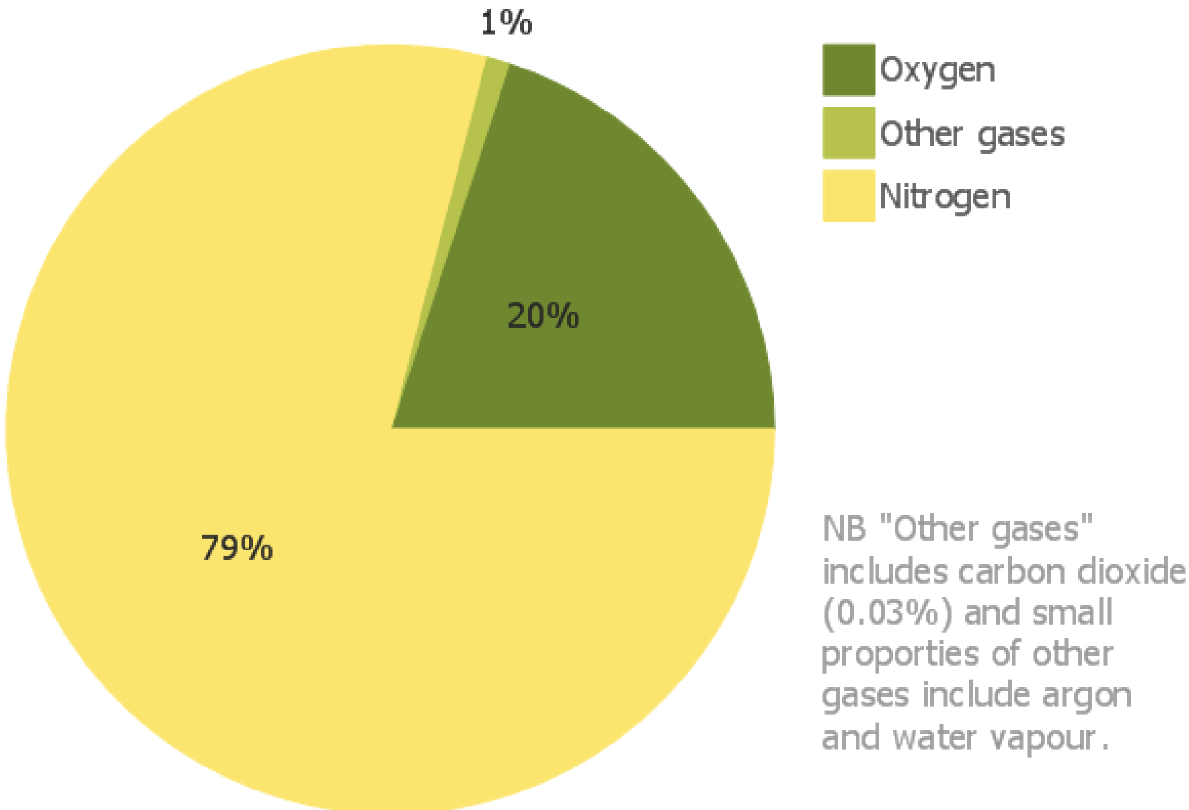
Earth's Atmosphere: Composition, Climate & Weather

Astronauts aboard the International Space Station took this image showing Earth's atmosphere and moon on July 31, 2011.

(Image: © ISS Crew Earth Observations Experiment and Image Science & Analysis Laboratory/Johnson Space Center.)

Earth is the only planet in the solar system with an atmosphere that can sustain life. The blanket of gases not only contains the air that we breathe but also protects us from the blasts of heat and radiation emanating from the sun. It warms the planet by day and cools it at night. Earth's atmosphere is about 300 miles (480 kilometers) thick, but most of it is within 10 miles (16 km) the surface. Air pressure decreases with altitude. At sea level, air pressure is about 14.7 pounds per square inch (1 kilogram per square centimeter). At 10,000 feet (3 km), the air pressure is 10 pounds per square inch (0.7 kg per square cm). There is also less oxygen to breathe.

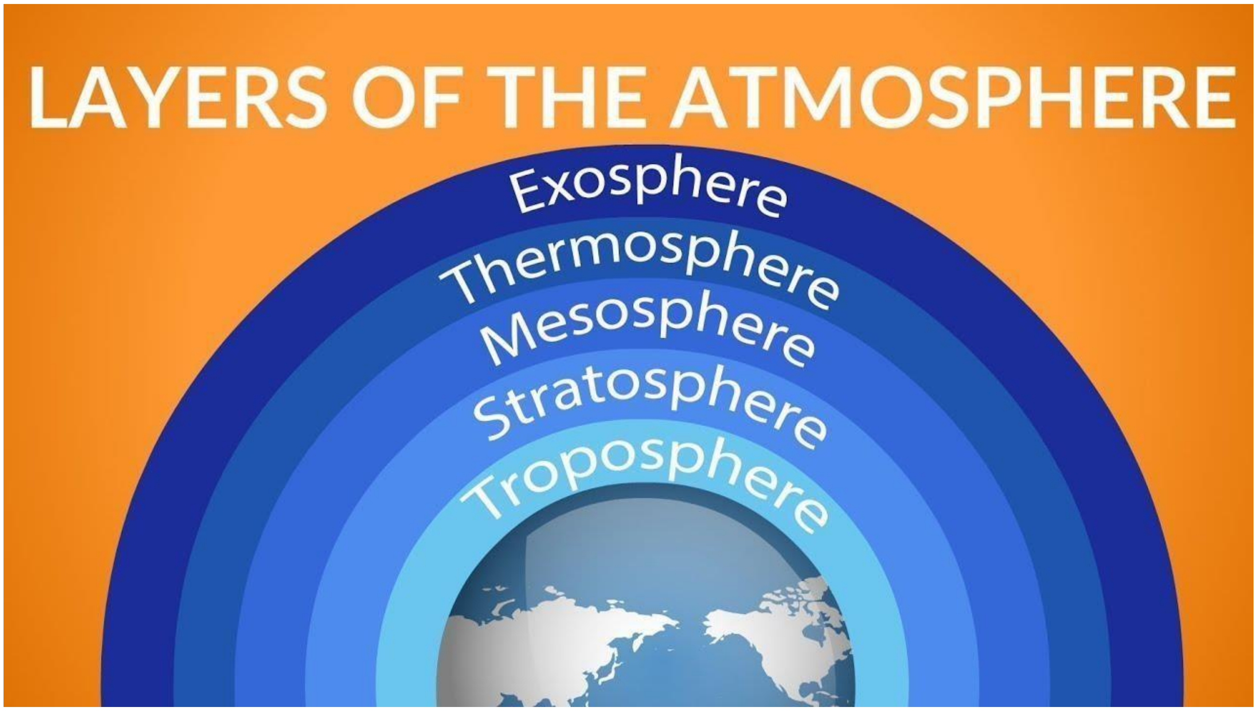
Composition of air



According to NASA, the gases in Earth's atmosphere include:

- Nitrogen — 78 percent
- Oxygen — 21 percent
- Argon — 0.93 percent
- Carbon dioxide — 0.04 percent
- Trace amounts of neon, helium, methane, krypton and hydrogen, as well as water vapor

The different layers of the atmosphere



The atmosphere can be divided into layers based on its temperature, as shown in the figure below.

These layers are the troposphere, the stratosphere, the mesosphere and the thermosphere.

A further region, beginning about 500 km above the Earth's surface, is called the exosphere.

The red line on the figure below shows how temperature varies with height (the temperature scale is given along the bottom of the diagram). The scale on the right shows the pressure. For example, at a height of 50 km, the pressure is only about one thousandth of the pressure at the ground.

The Troposphere

This is the lowest part of the atmosphere - the part we live in. It contains most of our weather - clouds, rain, snow. In this part of the atmosphere the temperature gets colder as the distance above the earth increases, by about 6.5°C per kilometre. The actual change of temperature with height varies from day to day, depending on the weather.

The troposphere contains about 75% of all of the air in the atmosphere, and almost all of the water vapour (which forms clouds and rain). The decrease in temperature with height is a result of the decreasing pressure. If a parcel of air moves upwards it expands (because of the lower pressure).

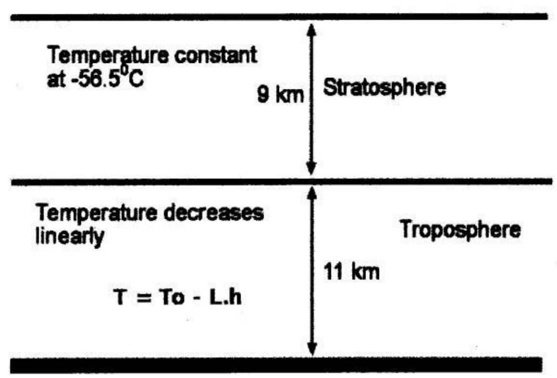
When air expands it cools. So air higher up is cooler than air lower down.

The lowest part of the troposphere is called the boundary layer. This is where the air motion is determined by the properties of the Earth's surface. Turbulence is generated as the wind blows over the Earth's surface, and by thermals rising from the land as it is heated by the sun. This turbulence redistributes heat and moisture within the boundary layer, as well as pollutants and other constituents of the atmosphere.

The top of the troposphere is called the tropopause. This is lowest at the poles, where it is about 7 - 10 km above the Earth's surface. It is highest (about 17 - 18 km) near the equator.

The Stratosphere

This extends upwards from the tropopause to about 50 km. It contains much of the ozone in the atmosphere. The increase in temperature with height occurs because of absorption of ultraviolet (UV) radiation from the sun by this ozone. Temperatures in the stratosphere are highest over the summer pole, and lowest over the winter pole.



By absorbing dangerous UV radiation, the ozone in the stratosphere protects us from skin cancer and other health damage. However chemicals (called CFCs or freons, and halons) which were once used in refrigerators, spray cans and fire extinguishers have reduced the amount of ozone in the stratosphere, particularly at polar latitudes, leading to the so-called "Antarctic ozone hole".

Now humans have stopped making most of the harmful CFCs we expect the ozone hole will eventually recover over the 21st century, but this is a slow process.

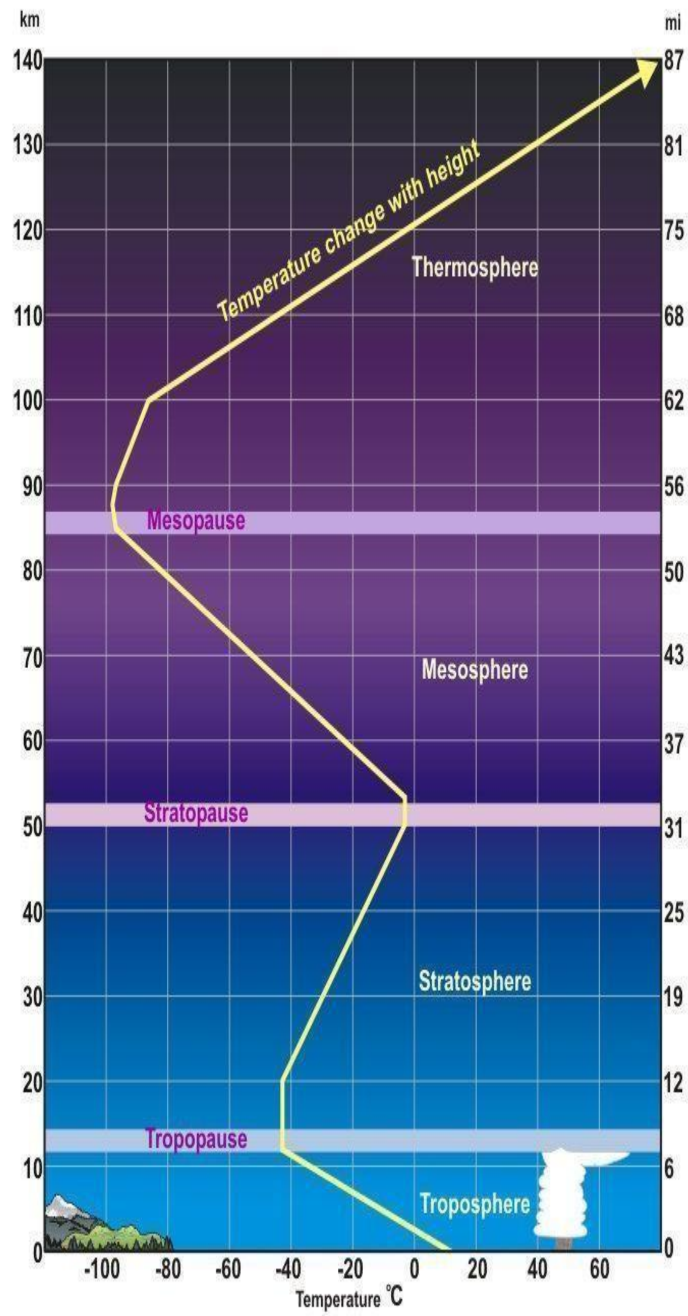
The Mesosphere

The region above the stratosphere is called the mesosphere. Here the temperature again decreases with height, reaching a minimum of about -90°C at the "mesopause".

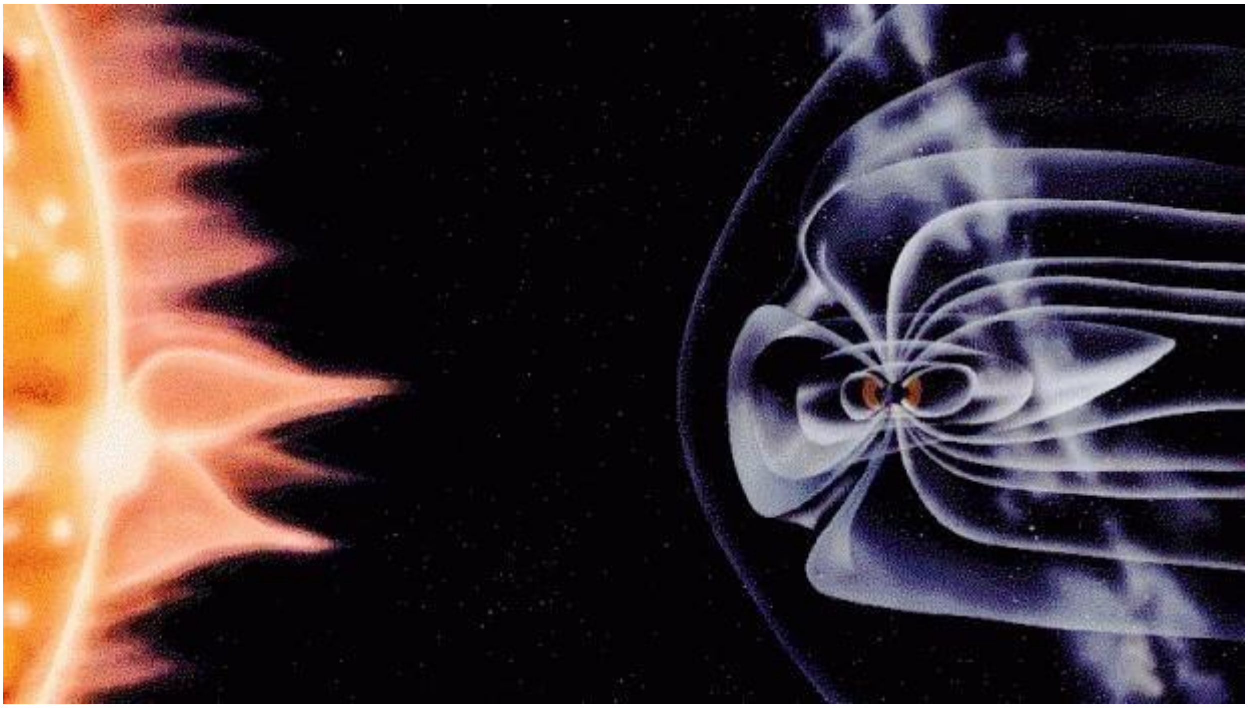
The Thermosphere and Ionosphere

The Exosphere

The region above about 500 km is called the exosphere. It contains mainly oxygen and hydrogen atoms, but there are so few of them that they rarely collide - they follow "ballistic" trajectories under the influence of gravity, and some of them escape right out into space.



The Magnetosphere



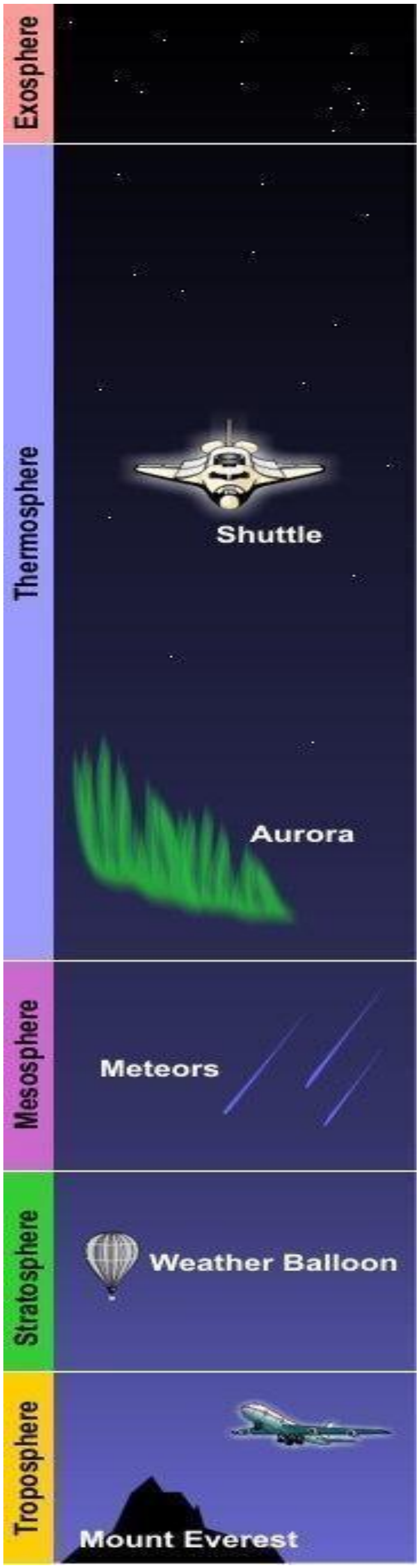
The earth behaves like a huge magnet. It traps electrons (negative charge) and protons (positive), concentrating them in two bands about 3,000 and 16,000 km above the globe - the Van Allen "radiation" belts. This outer region surrounding the earth, where charged particles spiral along the magnetic field lines, is called the magnetosphere.

Earth, Venus and Mars

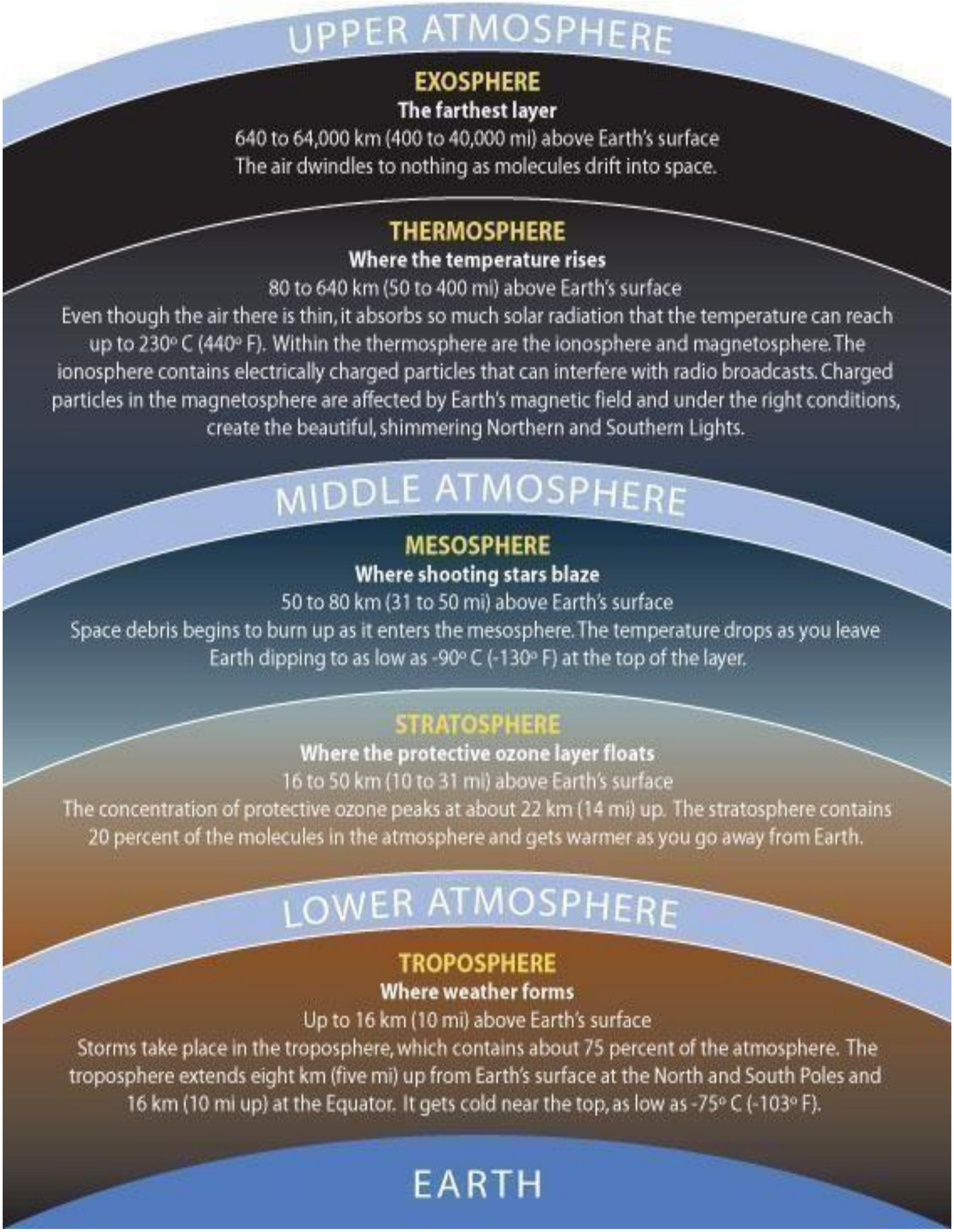
To better understand the formation and composition of Earth, scientists sometimes compare our planet with Venus and Mars. All three of these planets are rocky in nature and are part of the inner solar system, meaning that they are in between the sun and the asteroid belt.

Venus has an almost fully carbon dioxide atmosphere, with traces of nitrogen and sulfuric acid. The planet, however, also has a runaway greenhouse effect on its surface. Spacecraft have to be heavily reinforced to survive the crushing pressure (90 times heavier than Earth), and the ovenlike temperatures (872 Fahrenheit or 467 Celsius), found at its surface. The clouds are also so thick that the surface is invisible in visible light. Because not much sun reaches the surface, this means that Venus has no significant seasonal temperature changes.

Mars also has a mostly carbon dioxide atmosphere, with traces of nitrogen, argon, oxygen, carbon monoxide and some other gases. On this planet, the atmosphere is about 100 times thinner than



Earth's — a very different situation from the ancient past, when geological evidence shows that water used to flow on the surface more than 4.5 billion years ago. Scientists suggest that the Martian atmosphere may have thinned over time, either because the sun stripped away the lighter molecules in the atmosphere, or because a huge impact by an asteroid or comet catastrophically stripped the atmosphere. Mars undergoes temperature swings influenced by how much sunlight reaches the surface, which also affects its polar ice caps (another great influence on the atmosphere.) Scientists routinely compare small, rocky exoplanets to Earth, Venus and Mars to get a better sense of their habitability. The routinely accepted definition of "habitability" is that a planet is close enough to the star for liquid water to exist on its surface. Too far, and the water turns icy; too close, and the water evaporates. However, habitability not only depends on the star-planet distance, but also the planet's atmosphere, the star's variability, and other factors.


UPPER ATMOSPHERE
EXOSPHERE
The farthest layer
640 to 64,000 km (400 to 40,000 mi) above Earth's surface
The air dwindles to nothing as molecules drift into space.
THERMOSPHERE
Where the temperature rises
80 to 640 km (50 to 400 mi) above Earth's surface
Even though the air there is thin, it absorbs so much solar radiation that the temperature can reach up to 230° C (440° F). Within the thermosphere are the ionosphere and magnetosphere. The ionosphere contains electrically charged particles that can interfere with radio broadcasts. Charged particles in the magnetosphere are affected by Earth's magnetic field and under the right conditions, create the beautiful, shimmering Northern and Southern Lights.
MIDDLE ATMOSPHERE
MESOSPHERE
Where shooting stars blaze
50 to 80 km (31 to 50 mi) above Earth's surface
Space debris begins to burn up as it enters the mesosphere. The temperature drops as you leave Earth dipping to as low as -90° C (-130° F) at the top of the layer.
STRATOSPHERE
Where the protective ozone layer floats
16 to 50 km (10 to 31 mi) above Earth's surface
The concentration of protective ozone peaks at about 22 km (14 mi) up. The stratosphere contains 20 percent of the molecules in the atmosphere and gets warmer as you go away from Earth.
LOWER ATMOSPHERE
TROPOSPHERE
Where weather forms
Up to 16 km (10 mi) above Earth's surface
Storms take place in the troposphere, which contains about 75 percent of the atmosphere. The troposphere extends eight km (five mi) up from Earth's surface at the North and South Poles and 16 km (10 mi up) at the Equator. It gets cold near the top, as low as -75° C (-103° F).
EARTH

SUMMARY OF ATMOSPHERE

1. The troposphere is the lowest layer of our atmosphere. Starting at ground level, it extends upward to about 10 km (6.2 miles or about 33,000 feet) above sea level. We humans live in the troposphere, and nearly all weather occurs in this lowest layer. Most clouds appear here, mainly because 99% of the water vapor in the atmosphere is found in the troposphere.

   Air pressure drops, and temperatures get colder, as you climb higher in the troposphere.

2. The stratosphere is a layer of Earth's atmosphere. It is the second layer of the atmosphere as you go upward. The troposphere, the lowest layer, is right below the stratosphere. The next higher layer above the stratosphere is the mesosphere.

3. The mesosphere is a layer of Earth's atmosphere. The mesosphere is directly above the stratosphere and below the thermosphere. It extends from about 50 to 85 km (31 to 53 miles) above our planet.

4. Temperature decreases with height throughout the mesosphere. The coldest temperatures in Earth's atmosphere, about -90° C (-130° F), are found near the top of this layer.

5. The thermosphere is the layer in the Earth's atmosphere directly above the mesosphere and below the exosphere. Within this layer of the atmosphere, ultraviolet radiation causes photoionization/photodissociation of molecules, creating ions; the thermosphere thus constitutes the larger part of the ionosphere.

6. The ionosphere is not a distinct layer like the others mentioned above. Instead, the ionosphere is a series of regions in parts of the mesosphere and thermosphere where highenergy radiation from the Sun has knocked electrons loose from their parent atoms and molecules. The electrically charged atoms and molecules that are formed in this way are called ions, giving the ionosphere its name and endowing this region with some special properties.

7. The exosphere is the uppermost region of Earth's atmosphere as it gradually fades into the vacuum of space. Air in the exosphere is extremely thin - in many ways it is almost the same as the airless void of outer space.

8. The magnetosphere is the region of space surrounding Earth where the dominant magnetic field is the magnetic field of Earth, rather than the magnetic field of interplanetary space.

The magnetosphere is formed by the interaction of the solar wind with Earth's magnetic field.

TOPIC 2

Equation of state

In physics and thermodynamics, an equation of state is a thermodynamic equation relating state variables which describe the state of matter under a given set of physical conditions, such as pressure, volume, temperature (PVT), or internal energy. Equations of state are useful in describing the properties of fluids, mixtures of fluids, solids, and the interior of stars.

At present, there is no single equation of state that accurately predicts the properties of all substances under all conditions. An example of an equation of state correlates densities of gases and liquids to temperatures and pressures, known as the ideal gas law, which is roughly accurate for weakly polar gases at low pressures and moderate temperatures. This equation becomes increasingly inaccurate at higher pressures and lower temperatures, and fails to predict condensation from a gas to a liquid.

Another common use is in modeling the interior of stars, including neutron stars, dense matter (quark–gluon plasmas) and radiation fields. A related concept is the perfect fluid equation of state used in cosmology.

Equations of state can also describe solids, including the transition of solids from one crystalline state to another.

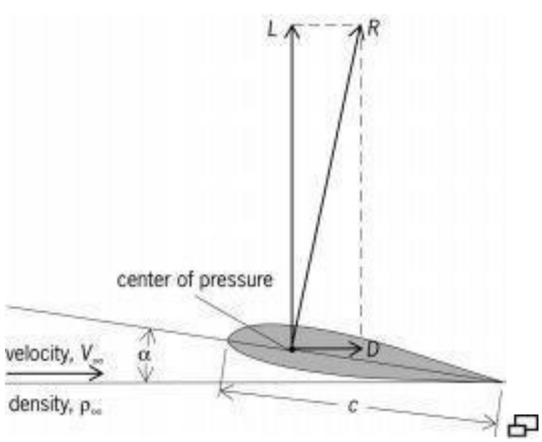
In a practical context, equations of state are instrumental for PVT calculations in process engineering problems, such as petroleum gas/liquid equilibrium calculations. A successful PVT model based on a fitted equation of state can be helpful to determine the state of the flow regime, the parameters for handling the reservoir fluids, and pipe sizing.

Measurements of equation-of-state parameters, especially at high pressures, can be made using lasers.

Aerodynamic force

The force exerted on a body whenever there is a relative velocity between the body and th e air. There are only two basic sources of aerodynamic force: the pressure distribution and the fri ctional shear stress distribution exerted by the airflow on the body surface. The pressure exerted by the air at a point on the surface acts perpendicular to the surface at that point; and the shear str ess, which is due to the frictional action of the air rubbing against the surface, acts tangentially to the surface at that point. The distribution of pressure and shear stress represent a distributed load over the surface. The net aerodynamic force on the body is due to the net imbalance between the se distributed loads as they are summed (integrated) over the entire surface.

For purposes of discussion, it is convenient to consider the aerodynamic force on an airfo il (see illustration). The net resultant aerodynamic force *R* acting through the center of pressure o n the airfoil represents mechanically the same effect as that due to the actual pressure and shear s tress loads distributed over the body surface. The velocity of the airflow V_∞ is called the freestream velocity or the freestream relative wind. By definition, the component of *R* perpendicular to the relative wind is the l ift, *L*, and the component of *R* parallel to the relative wind is the drag *D*. The orientation of the b ody with respect to the direction of the free stream is given by the angle of attack, α. The magnit ude of the aerodynamic force *R* is governed by the density &rgr;$_\infty$ and velocity of the free stream, the size of the body, and the angle of attack.



Resultant aerodynamic force (*R*), and its resolution into lift (*L*) and drag (*D*) components

An important measure of aerodynamic efficiency is the ratio of lift to drag, *L*/*D*. The high er the value of *L*/*D*, the more efficient is the lifting action of the body. The value of *L*/*D* reaches a maximum, denoted by $(L/D)_{max}$, at a relatively low angle of attack. Beyond a certain angle the l ift decreases with increasing α. In this region, the wing is said to be stalled. In the stall region the flow has separated from the top surface of the wing, creating a type of slowly recirculating deadair region, which decreases the lift and substantially increases the drag.

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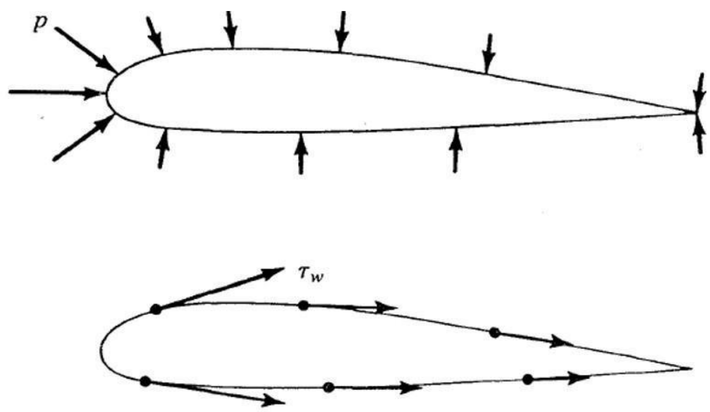

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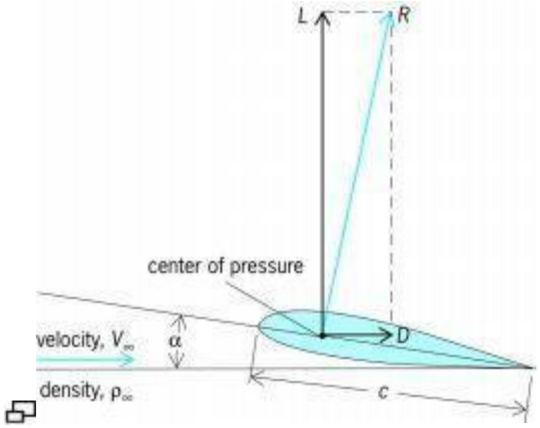

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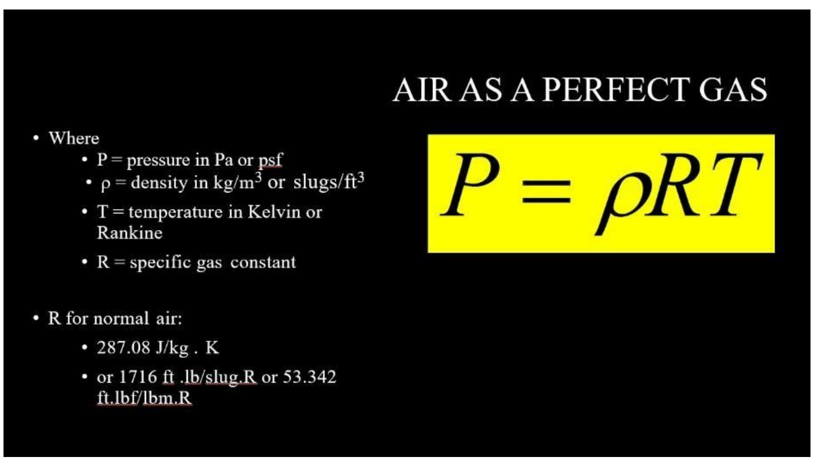

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MODULE 2

TOPIC 1

THE MYTH OF DAEDALUS AND ICARUS

The myth of **Daedalus and Icarus** is one of the most known and fascinating Greek Myths, as it consists of both historical and mythical details.

While in Crete Daedalus created the plan for the Minoan Palace of Knossos, one of the most important archaeological sites in Crete and Greece today. It was a magnificent architectural design and building, of 1,300 rooms, decorated with stunning frescoes and artifacts, saved until today. The sculpture of Ariadne in Knossos and many others in Elounda and Karia are also his.

King Minos and Daedalus had great understanding at first, but their relationships started deteriorating at some point; there are several versions explaining this sudden change, although the most common one is that Daedalus was the one who advised Princess Ariadne to give Theseus the thread that helped him come out from the infamous Labyrinth, after killing the Minotaur.

The Labyrinth was a maze built by Daedalus; King Minos wanted a building suitable to imprison the mythical monster Minotaur, and according to the myth, he used to imprison his enemies in the labyrinth, making sure that they would be killed by the monster.

Minos was infuriated when found out about the betrayal and imprisoned Daedalus and his son Icarus in the Labyrinth.

The Flight Of Daedalus And Icarus

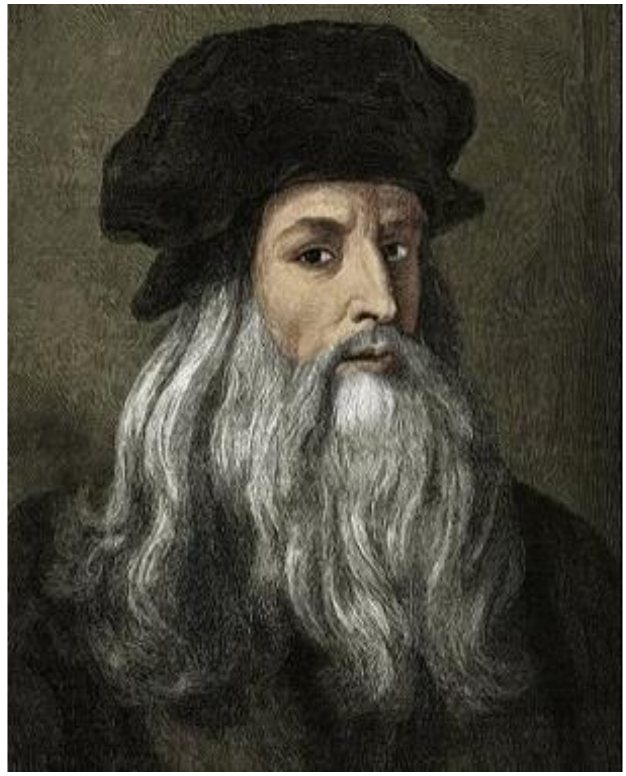
Icarus was the young son of Daedalus and Nafsicrate, one of King Minos' servants. Daedalus was way too smart and inventive, thus, he started thinking how he and Icarus would escape the Labyrinth. Knowing that his architectural creation was too complicated, he figured out that they could not come out on foot. He also knew that the shores of Crete were perfectly guarded, thus, they would not be able to escape by sea either. The only way left was the air.

Daedalus managed to create gigantic wings, using branches of osier and connected them with wax. He taught Icarus how to fly, but told him to keep away from the sun because the heat would make the wax melt, destroying the wings. Daedalus and Icarus managed to escape the Labyrinth and flew to the sky, free. The flight of Daedalus and Icarus was the first time that man managed to fight the laws of nature and beat gravity.

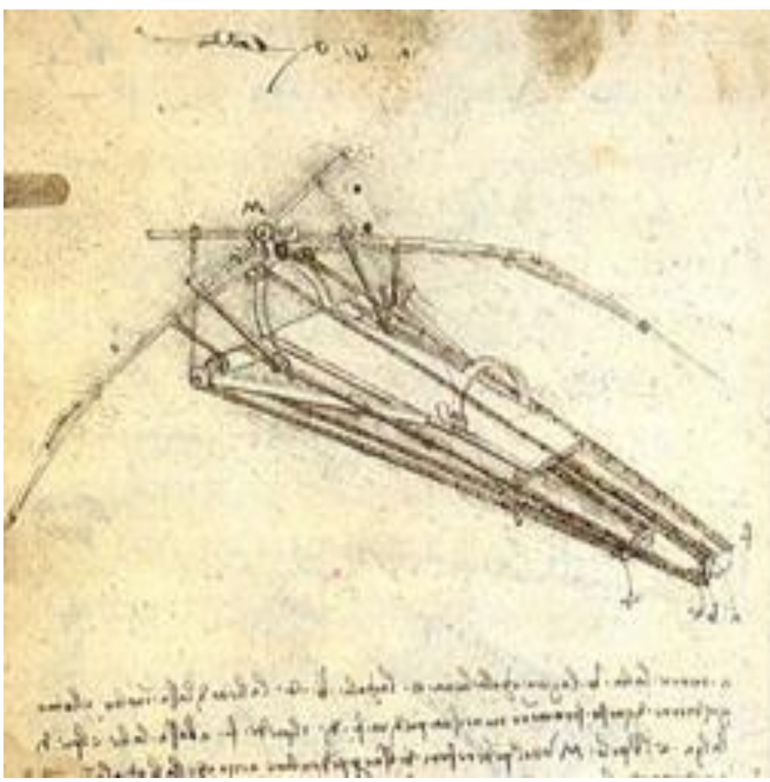
Icarus Death

Although he was warned, Icarus was too young and too enthusiastic about flying. He got excited by the thrill of flying and carried away by the amazing feeling of freedom and started flying high to salute the sun, diving low to the sea, and then up high again. His father Daedalus was trying in vain to make young Icarus to understand that his behavior was dangerous, and Icarus soon saw his wings melting. Icarus fell into the sea and drowned. The Icarian Sea, where he fell, was named after him and there is also a nearby small island called Icaria.

Flying Machine



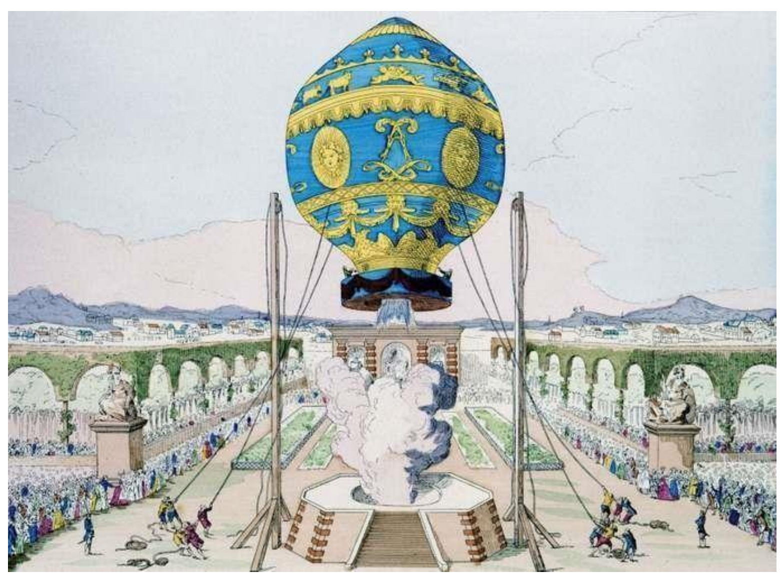
Of Leonardo da Vinci's many areas of study, perhaps this Renaissance man's favorite was the area of aviation. Da Vinci seemed truly excited by the possibility of people soaring through the skies like birds. One of da Vinci's most famous inventions, the flying machine (also known as the "ornithopter") ideally displays his powers of observation and imagination, as well as his enthusiasm for the potential of flight. The design for this invention is clearly inspired by the flight of winged animals, which da Vinci hoped to replicate. In fact, in his notes, he mentions bats, kites and birds as sources of inspiration. Perhaps the inspiration of the bat shines through the most, as the two wings of the device feature pointed ends commonly associated with the winged creature. Leonardo da Vinci's flying machine had a wingspan that exceeded 33 feet, and the frame was to be made of pine covered in raw silk to create a light but sturdy membrane. The pilot would lie face down in the center of the invention on a board. To power the wings, the pilot would pedal a crank connected to a rod-and-pulley system. The machine also had a hand crank for increased energy output, and a head piece for steering. As the busy pilot spins cranks with his hands and feet, the wings of the machine flap. The inspiration of nature in the invention is apparent in the way the wings were designed to twist as they flapped. Unfortunately, as da Vinci himself might have realized, while the flying machine may have flown once it was in the air, a person could never have created enough power to get the device off the ground.



Montgolfier Brothers

Joseph-Michel and Jacques-Étienne Montgolfier, also called the **Montgolfier brothers**, (respectively, born Aug. 26, 1740, Annonay, France—died June 26, 1810, Balarucles-Bains; born Jan. 6, 1745, Annonay, France— died Aug. 2, 1799, enroute from Lyon to Annonay), French brothers who were pioneer developers of the hot-air balloon and who conducted the first untethered flights. Modifications and improvements of the basic Montgolfier design were incorporated in the construction of larger balloons that, in later years, opened the way to exploration of the upper atmosphere. Joseph and Étienne were 2 of the 16 children of Pierre Montgolfier, whose prosperous paper factories in the small town of Vidalon, near Annonay, in southern France, ensured the financial support of their balloon experiments. While carrying on their father's paper business, they maintained their interest in scientific experimentation.

In 1782 they discovered that heated air, when collected inside a large lightweight paper or fabric bag, caused the bag to rise into the air. The Montgolfiers made the first public demonstration of this discovery on June 4, 1783, at the marketplace in Annonay. They filled their balloon with heated air by burning straw and wool under the opening at the bottom of the bag. The balloon rose into the air about 3,000 feet (1,000 metres), remained there some 10 minutes, and then settled to the ground more than a mile and a half from where it rose. The Montgolfiers traveled to Paris and then to Versailles, where they repeated the experiment with a larger balloon on Sept. 19, 1783, sending a sheep, a rooster, and a duck aloft as passengers. The balloon floated for about 8 minutes and landed safely about 2 miles (3.2 kilometres) from the launch site. On Nov. 21, 1783, the first manned untethered flight took place in a Montgolfier balloon with Pilatre de Rozier and François Laurent, marquis d'Arlandes, as passengers. The balloon sailed over Paris for 5.5 miles (9 kilometres) in about 25 minutes.



Montgolfier balloon JeanFrançois Pilâtre de Rozier and François Laurent, marquis d'Arlandes, ascending in a Montgolfier balloon at the Château de la Muette, Paris, November 21,

1783. © Photos.com/Jupiterimages

The two brothers were honoured by the French Académie des Sciences. They published books on aeronautics and continued their scientific careers. Joseph invented a calorimeter and the hydraulic ram, and Étienne developed a process for manufacturing vellum.

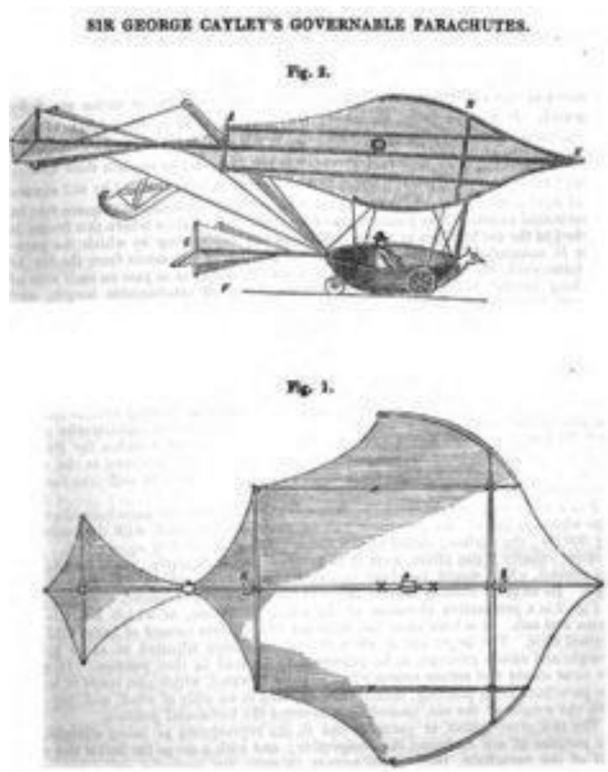
Jacques Charles

Jacques-Alexandre-César Charles was a mathematician and physicist remembered for his pioneering work with gases and hydrogen balloon flights. Charles was born on November 12, 1746, in Beaugency, Loiret, France; his first occupation was as a clerk at the Ministry of Finance in Paris. However, his interests eventually turned to science. In the late 1700s ballooning became a major preoccupation of France and

other industrialized nations. In early June 1783 the Montgolfier brothers launched the first successful hot-air balloon in Paris. Charles, who was interested in aeronautics, understood the concept of buoyancy and also was aware of Henry Cavendish's discovery of hydrogen, an element some fourteen times lighter than air, seventeen years earlier. On August 27, 1783, Charles launched the first hydrogen-filled balloon using gas produced by the reaction of sulfuric acid on iron filings. Among the 50,000 witnesses of this event was Benjamin Franklin, then residing in Paris as the U.S. ambassador to France. When the balloon returned to Earth in the French countryside, it was reportedly attacked with axes and pitchforks by terrified peasants who believed it to be a monster from the skies. On November 21 of that same year the Montgolfier brothers launched the first hotair balloon with humans aboard, managing an altitude of less than 30 meters (98 feet). Charles, with the aid of brothers Nicholas and Aine Jean Robert, became the first human to ascend in a hydrogen balloon just ten days later. A far greater height of almost 3,000 meters (9,843 feet) was attained thanks to the superior lift of the hydrogen balloon Charles had designed and helped build.Charles is best known for his studies on how the volume of gases changes with temperature. The English scientist Robert Boyle had many years earlier determined the inverse relationship between the volume V and pressure P of a gas when temperature T is held constant. In 1662 he published the results that would later come to be known as Boyle's law ($V \alpha 1/ P$ at constant T). During the winter of 1787 Charles studied oxygen, nitrogen, hydrogen, and carbon dioxide and found that the volume of all these gases increased identically with higher temperature when pressure was held constant ($V \alpha T$ at constant P). Charles did not publish the results of his work at the time, but another French scientist, Joseph-Louis Gay-Lussac, eventually learned of them. When Gay-Lussac did more extensive and precise experiments and published his similar findings in 1802 (as did the English scientist John Dalton), he acknowledged Charles's original work. Thus, the law governing the thermal expansion of gases, although sometimes called Gay-Lussac's law, is more commonly known as Charles's law.

While most of Charles's papers were on mathematics, he was ultimately an avid scientist and inventor. He duplicated a number of experiments that Franklin and others had completed on electricity and designed several instruments, including a new type of hydrometer for measuring densities and a reflecting goniometer for measuring the angles of crystals. Charles was elected to France's Academy of Sciences in 1785 and later became professor of physics at the Conservatoire des Arts et Métiers. He died in Paris on April 7, 1823.

Sir George Cayley, The Father of Aeronautics

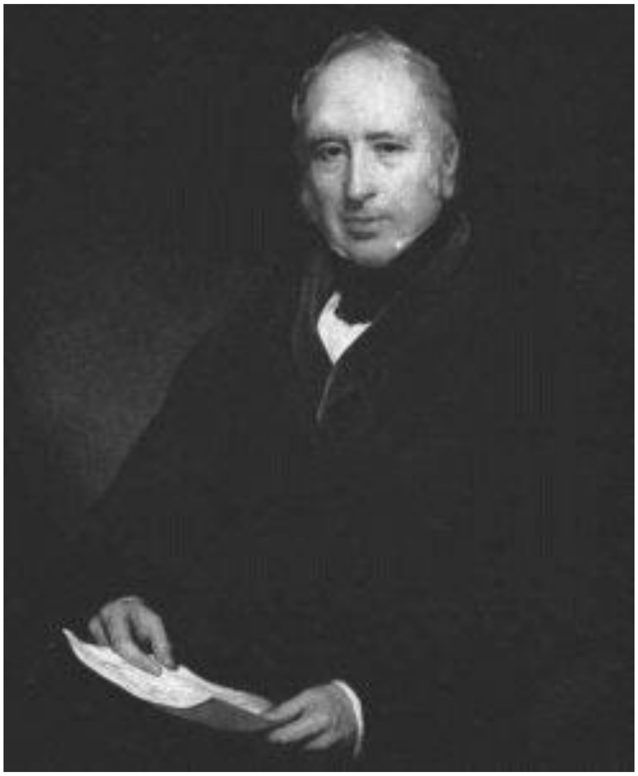


According to the account of Cayley's granddaughter, the somewhat reluctant pilotpassenger was a coachman, John Appleby. He took his place in a little boat-like carriage slung under the wings; the glider was duly launched, drawn by a galloping horse, and in a flight that must have only taken seconds, yet doubtless felt like hours to the terrified coachman, the machine flew 900 feet across the valley. It was the first recorded flight of a fixedwing aircraft carrying an adult.

After its brief and successful flight, the glider crashed. The coachman survived. His words on landing have not been recorded. However, in a very short space of time he was greeting his employer with a heartfelt request: "Please, Sir George, I wish to give notice. I was hired to drive, not to fly!" Sir George Cayley's glider had proved a lot more unpredictable than a four-in-hand.

The coachman's airborne journey across Brompton Dale was the culmination of Sir George

Cayley's lifetime of devotion to understanding the principles of flight. In fact, if it hadn't been for the fact that Cayley was nearly 80, he would probably have taken the coachman's place himself.



Born in 1773, Cayley was the 6th holder of the Cayley baronetcy. He lived at Brompton Hall and was a local landowner of substance, having inherited several estates on the death of his father. He was interested in a phenomenal range of subjects, mostly related to engineering. An imaginative inventor as well as a talented engineer, Cayley is best known for his research into the principles and mechanics of flying, as well as the practical projects he developed later from his early theoretical work.

Cayley's contribution to the history of manned flight is so important that he is recognized by many as "The Father of Aeronautics". As early as 1799, he had grasped the basic issue of heavier than air flight, that lift should balance weight and thrust must overcome drag, which should be minimised. His summary was presented in his treatise on flight, *On Aerial Navigation*, published in the early years of the 19th century: "*the whole problem is confined within these limits, viz, to make a surface support a given weight by the application of power to the air*."

Cayley had identified and defined the four forces acting on an aeroplane in flight: lift, weight, thrust and drag. Recent research, from 2007, suggests that sketches from his schoolboy days might indicate he was already aware of the principles of a lift-generating plane by 1792.

His conclusions were based on observations and calculations of the forces required to keep those true flying machines, birds, aloft. From these investigations, he was able to set out a design for an aero plane that had all the elements that are recognizable in modern planes, including fixed wings, and lift, propulsion and control systems.

Cayley's 1799 Coin

In order to record his ideas, in 1799 Cayley engraved an image of his aircraft design on a small disc of silver. The disc, which is now in The Science Museum in London, shows a recognizable aircraft with fixed wings, an underslung carriage like a boat, flappers for propulsion and a cross-shaped tail. On this side, Cayley also engraved his initials. On the other side, he recorded a diagram of the four forces acting on the aircraft while flying in a direct line.

Cayley worked on models of his ideas, successfully hand-launching one of them and flying it in 1804. This was recognised by one aeronautical historian, C. H. Gibbs-Smith, as the first "true aeroplane flight" in history. The wing surface was about 5 square feet, and kite-shaped. At the rear the glider had an adjustable tail with stabilisers and a vertical fin.

In parallel with his interest in fixed-wing aircraft, Cayley was also, like several other inventors of his day, interested in the principles of the ornithopter, based on the idea of flapping to create flight. In France, Launoy and Beinvenu had created a twin counter-rotation model using turkey feathers. Apparently independently, Cayley developed a rotor helicopter model in the

1790s, calling it his "Aerial Carriage". *Model of Sir George Caley's "Aerial Carriage", 1843. Licensed under the Creative Commons Attribution-Share Alike 3.0 Unported license.*

From 1810 onwards, Cayley was publishing his three-part series *On Aerial Navigation.* It was also at this point that Cayley's visionary side began to show. He knew by then that manpower alone would never be sufficient to successfully fly an aircraft. However much the "make a big set of wings and flap them like hell" school of flying, as portrayed by Jacob Degen (who cheated with a hydrogen balloon) believed (or pretended to believe), that flapping was the answer, Cayley knew otherwise. He turned his attention to the issue of power for fixedwing aircraft that were heavier then air.

Here, he was genuinely too far ahead of his time. Lighter-than-air machines such as balloons were, of course flying successfully. Heavier-than-air machines required power, and the only power available at that point was that produced by the emerging technology of steam. He did give some consideration to using a Boulton and Watt steam engine for powering an aircraft.

More significantly, with remarkable prescience Cayley foresaw and even described the principles of the internal combustion engine. He made attempts to invent hot air engines, using various power sources including gunpowder. Had there been a lightweight engine available to him,

Cayley would almost undoubtedly have created the first manned and powered aircraft.

At the same time as his aeronautical investigations, his enquiring and practical mind led him to devise or develop lightweight tension-spoke wheels, a type of caterpillar tractor, automatic signals for railway crossings and many other items that we take for granted today. He was also interested in architecture, land drainage and improvement, optics and electricity.

Cayley also gave consideration to balloon flight, coming up with streamlined designs that were essentially prototype airships powered by steam. He also had the idea of using separate gas bags on airships as a safety feature to reduce gas loss through damage. Thus, his ideas prefigured airships by many years.

The famous flight that took his employee aloft in 1853 was preceded by one in 1849 with a ten-year-old boy on board. His glider designs were based on the model he had created so many years before, in 1799.

There is some discussion about who was actually involved in the flights – some accounts say it was his grandson who participated in the 1853 flight, not his coachman, which seems a bit of a profligate way to behave with one's relatives, even in the cause of science. Cayley undoubtedly had the true scientific spirit, for he was a founder member of both the Yorkshire Philosophical Society and the Scarborough Philosophical Society and also helped to found and promote the British Association for the Advancement of Science in 1831.

In fact, Cayley felt it was a "national disgrace" that there was no aeronautical society and attempted to to set one up several times. He wanted to claim for Britain "*the glory of being the first to establish the dry navigation of the universal ocean of the terrestrial atmosphere*". In describing his own machines, Cayley could be lyrical as well as scientific. He wrote of his glider design: "*It was beautiful to see this noble white bird sailing majestically from the top of a hill to any given point of the plain below it with perfect steadiness and safety*."

Cayley lived in a great age for engineers, both in Britain and abroad. He may have had more financial resources than the Stephensons of north east England, James Watt, the lighthouse Stevensons of Scotland or many other famous names of the time. However, what comes through clearly in the work of all the memorable pioneers of this period is their egalitarian scientific spirit as well as their commercially competitive ambition. Individuals like Cayley understood these were experiments to which everyone should have access and made sure that his research was publicly available.

His contribution was acknowledged, too. As Wilbur Wright commented in 1909: “*About 100 years ago, an Englishman, Sir George Cayley, carried the science of flight to a point which it had never reached before and which it scarcely reached again during the last century*.”

When not taking his seat in parliament as the Whig member for Brompton from 1832 to 1835, some of the most turbulent years in British political history, Cayley spent most of his time at Brompton, involved in his various experiments and research interests. He died there on December 15th 1857. After his death, his colleague the Duke of Argyll finally enabled Cayley’s dream of a society dedicated to aeronautical research to come true, with the foundation of the Aeronautical Society of Great Britain.

Lilienthal Glider

The most significant pre-Wright brother’s aeronautical experimenter was the German glider pioneer, Otto Lilienthal. Lilienthal was trained in the highly regarded German technical education system and earned his living as a professional engineer. He began research in aeronautics with his brother Gustave in the late 1860s, investigating the mechanics and aerodynamics of bird flight. In the 1870s he conducted a series of experiments on wing shapes and gathered air pressure data using a whirling arm and in the natural wind. The research produced the best and most complete body of aerodynamic data of the day. Lilienthal also established definitively the widely held belief that a curved wing section, as opposed to a flat wing surface, was the optimum shape for generating lift. In 1889 he published his findings in a path breaking book called Der Vogelflug als Grundlage der Fliegekunst (Birdflight as the Basis of Aviation).

Lilienthal was not satisfied to restrict his work to the exploration of aerodynamic theory. Between 1891 and 1896, he put his research into practice in the form of a series of highly successful full-size glider trials. During this period Lilienthal made close to 2,000 brief flights in 16 different glider designs based on his aerodynamic investigations. Most were monoplanes with stabilizing tail surfaces mounted at the rear. He also tried a few biplane and folding wing designs, but the original monoplane glider, or Normal Segelapparat (standard sailing machine) as he called it, produced the best results. Lilienthal built at least eight gliders of this type.

The gliders had split willow frames covered with cotton twill fabric sealed with collodion to make the surface as airtight as possible. Collodion is a viscous solution of nitrated cellulose in a mixture of alcohol and ether that dries to form a tough elastic film. The wings ranged in area from 9 to 25 m2 (100 to 280 ft2), and could be folded to the rear for easier transport and storage. Control was achieved by shifting body weight, similar to modern hang glider practice. The pilot cradled himself vertically in a harness suspended below an elliptical opening between the wings. Swinging his legs from side to side and fore and aft, the pilot could adjust the center of gravity and thereby maintain equilibrium.

Lilienthal did most of his gliding from a manmade hill he had constructed near his home at Gross Lichterfelde, and from the hills surrounding the small village of Rhinow, about fifty miles from Berlin. His best efforts with these gliders covered more than 300 m (985 ft) and were

12 to 15 seconds in duration.

In the summer of 1896, Lilienthal's aeronautical experiments came to an abrupt and tragic end. On August 9, while soaring in one of his standard monoplane gliders, a strong gust of wind caused the craft to nose up sharply, stall, and crash from an altitude of 15 m (50 ft). Lilienthal suffered a broken spine and died the following day in a Berlin hospital.

As successful as they were, Lilienthal's glider designs had some inherent limitations that he would have had to confront had he lived and continued his work. The principal problem was his means of controlling the craft. Lilienthal's technique of shifting body weight to maintain equilibrium did place him ahead of other experimenters in that he recognized the need for a control system and gave attention to developing one. But, as revealed in his fatal crash, the control response of his method was very limited. Even more significant, shifting body weight as a means of control placed a severe restriction on the size of the aircraft. Because control was achieved by altering the aircraft's center of gravity as a result of repositioning the pilot's body weight, the weight of the aircraft had to be kept comparatively low. This presented a great problem in the design of a powered airplane. Any aircraft capable of lifting an engine and pilot, much less any sort of a payload, would be of a size so large that shifting body weight would be totally ineffectual.

Further, the airfoil of Lilienthal's gliders, although extensively tested and documented during his earlier aerodynamic research, was very inefficient in actual practice. Lilienthal always preferred a perfect arc for the shape of his glider wings with a very deep camber of 1 in 12. His investigations demonstrated that a curved surface was the most efficient shape, but he never abandoned the perfect arc in his gliders to experiment with parabolic airfoils, which later proved to be superior. The deeply cambered perfect arcs of Lilienthal's glider wings resulted in aerodynamic efficiency and stability problems.

Despite these unresolved issues, the impact of Lilienthal's aeronautical work upon the next generation of experimenters, the generation that would finally achieve heavier-than-air powered flight, was highly influential. With his pioneering aerodynamic research and his success in the air, Lilienthal had established a new starting point for anyone entering the field. Beyond his technical contributions, he sparked aeronautical advancement from a psychological point of view as well. He demonstrated unquestionably that gliding flight was possible. Granted, he was flying for only seconds at a time, but he was truly flying. Lilienthal's tentative trips through the air made headlines everywhere. Dramatic photographs showing Lilienthal soaring gracefully over hillsides appeared in newspapers and magazines the world over. The publicity made him quite a sensation in an age when, for most, human flight still seemed a distant possibility at best. This exposure and visible proof that a human being could actually fly contributed as much to spurring other experimenters forward as did Lilienthal's ground breaking aerodynamic research. He was a great inspiration to the Wright brothers in particular. They adopted his approach of glider experimentation and used his aerodynamic data as a starting point in their own research.

The Lilienthal glider in the NASM collection was built by the German experimenter in late 1895, early 1896. It was purchased from Lilienthal by the American newspaper magnate William Randolph Hearst in the spring of 1896. Hearst sponsored test flights of the glider on a Long Island estate in April and May 1896 in an effort to create publicity and boost the circulation of his newspaper, the New York Journal. Harry Bodine, a New Jersey athlete, made most of the flights, although Journal reporters and other spectators were also allowed to test their skill. Flights as long as 115 m (375 ft) at altitudes of up to 15 m (50 ft) were made with the glider.

Further flight testing, however, ceased after Lilienthal's death in August. Hearst then gave the glider to John Brisben Walker, editor of Cosmopolitan magazine, who displayed it at a New York Aero Club show in January 1906. Alexander Graham Bell suggested to

Walker that the Smithsonian Institution likely would be interested in pursuing acquisition of the Lilienthal glider. After the Smithsonian approached Walker on the matter, he presented it to the Smithsonian on February 2, 1906. Minor refurbishing was done in 1906 and 1928, and in 1967 the glider was completely restored. The horizontal tail is not original. The NASM Lilienthal glider is one of five remaining in the world.

Wright brothers

Wright brothers, American brothers, inventors, and aviation pioneers who achieved the first powered, sustained, and controlled airplane flight (1903). Wilbur Wright (April 16, 1867, near Millville, Indiana, U.S.—May 30, 1912, Dayton, Ohio) and his brother Orville Wright (August 19, 1871, Dayton—January 30, 1948, Dayton) also built and flew the first fully practical airplane (1905)

Early Glider Experiments

The ability of the Wright brothers to analyze a mechanical problem and move toward a solution was apparent from the outset of their work in aeronautics. The brothers realized that a successful airplane would require wings to generate lift, a propulsion system to move it through the air, and a system to control the craft in flight. Lilienthal, they reasoned, had built wings capable of carrying him in flight, while the builders of self-propelled vehicles were developing lighter and more powerful internal-combustion engines. The final problem to be solved, they concluded, was that of control.

Most aeronautical experimenters up to that time had sought to develop flying machines incorporating a measure of inherent stability, so that the aircraft would tend to fly a straight and level course unless the pilot intervened to change altitude or direction. As experienced cyclists, the Wrights preferred to place complete control of their machine in the hands of the operator.

Moreover, aware of the dangers of weight-shifting control (a means of controlling the aircraft by shifting the position of the pilot), the brothers were determined to control their machine through a precise manipulation of the centre of pressure on the wings. After considering various mechanical schemes for obtaining such control, they decided to try to induce a helical twist across the wings in either direction. The resulting increase in lift on one side and decrease on the other would enable the pilot to raise or lower either wing tip at will.

Their first experiments with “wing warping,” as the system would be called, were made with a small biplane kite flown in Dayton in the summer of 1899. Discovering that they could cause the kite to climb, dive, and bank to the right or left at will, the brothers began to design their first full-scale glider using Lilienthal’s data to calculate the amount of wing surface area required to lift the estimated weight of the machine and pilot in a wind of given velocity.

Realizing that Dayton, with its relatively low winds and flat terrain, was not the ideal place to conduct aeronautical experiments, the Wrights requested of the U.S. Weather Bureau (later the National Weather Service) a list of more suitable areas. They selected Kitty Hawk, an isolated village on the Outer Banks of North Carolina, which offered high average winds, tall dunes from which to glide, and soft sand for landings.

Tested in October 1900, the first Wright glider was a biplane featuring 165 square feet (15 square metres) of wing area and a forward elevator for pitch control. The glider developed less lift than expected, however, and very few free flights were made with a pilot on board. The brothers flew the glider as a kite, gathering information on the performance of the machine that would be critically important in the design of future aircraft.

Eager to improve on the disappointing performance of their 1900 glider, the Wrights increased the wing area of their next machine to 290 square feet (26 square metres). Establishing their camp at the foot of the Kill Devil Hills, 4 miles (6.5 km) south of Kitty Hawk, the brothers completed 50 to 100 glides in July and August of 1901. As in 1900, Wilbur made all the glides, the best of which covered nearly 400 feet (120 metres). The 1901 Wright aircraft was an improvement over its predecessor, but it still did not perform as well as their calculations had predicted. Moreover, the experience of 1901 suggested that the problems of control were not fully resolved.

Discouraged, but determined to preserve a record of their aeronautical work to date, Wilbur accepted Chanute's invitation to address the prestigious Western Society of Engineers. Wilbur's talk was delivered in Chicago on September 18, 1901, and was published as "Some Aeronautical Experiments" in the journal of the society. It indicated the extent to which the Wright brothers, in spite of their disappointments, had already moved beyond other flying machine experimenters.

Solving The Problems of Lift and Control

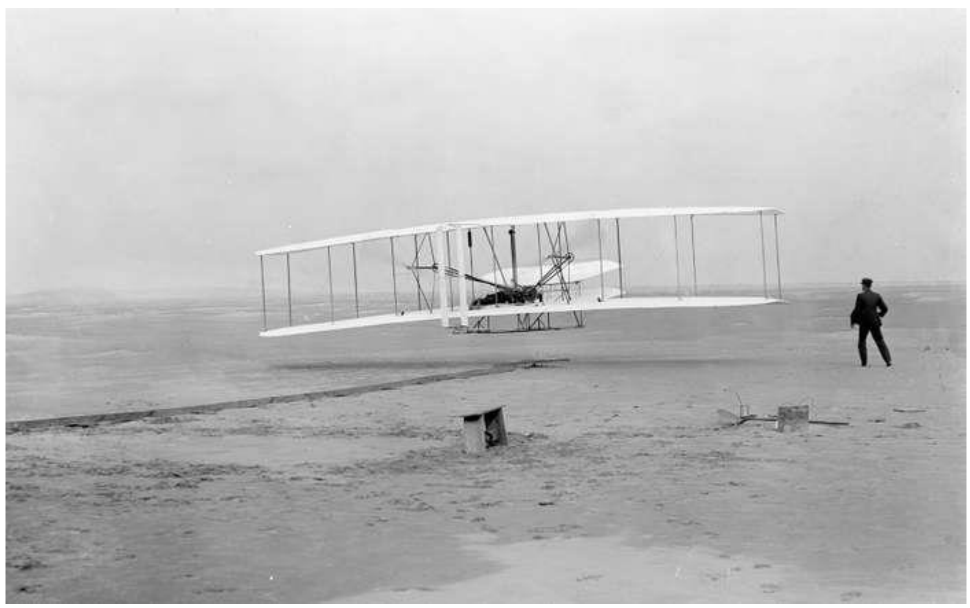
Realizing that the failure of their gliders to match calculated performance was the result of errors in the experimental data published by their predecessors, the Wrights constructed a small wind tunnel with which to gather their own information on the behaviour in an airstream of model wings of various shapes and sizes. The brilliance of the Wright brothers, their ability to visualize the behaviour of a machine that had yet to be constructed, was seldom more apparent than in the design of their wind-tunnel balances, the instruments mounted inside the tunnel that actually measured the forces operating on the model wings. During the fall and early winter of 1901 the Wrights tested between 100 and 200 wing designs in their wind tunnel, gathering information on the relative efficiencies of various airfoils and determining the effect of different wing shapes, tip designs, and gap sizes between the two wings of a biplane.

With the results of the wind-tunnel tests in hand, the brothers began work on their third full-scale glider. They tested the machine at the Kill Devil Hills camp in September and October of 1902. It performed exactly as the design calculations predicted. For the first time, the brothers shared the flying duties, completing 700–1,000 flights, covering distances up to 622.5 feet (189.75 metres), and remaining in the air for as long as 26 seconds. In addition to gaining significant experience in the air, the Wrights were able to complete their control system by adding a movable rudder linked to the wing-warping system.

Wright glider Side view of Wilbur Wright gliding in level flight in Kitty Hawk, North Carolina, on October 10, 1902. **Wright glider** Wilbur Wright executes a banking turn to the right in the Wright brothers' first fully controllable glider, at the Kill Devil Hills, North Carolina, October 24, 1902.

Powered, Sustained Flight

With the major aerodynamic and control problems behind them, the brothers pressed forward with the design and construction of their first powered machine. They designed and built a four-cylinder internal-combustion engine with the assistance of Charles Taylor, a machinist whom they employed in the bicycle shop. Recognizing that propeller blades could be understood as rotary wings, the Wrights were able to design twin pusher propellers on the basis of their windtunnel data. The brothers returned to their camp near the Kill Devil Hills in September 1903. They spent the next seven weeks assembling, testing, and repairing their powered machine and conducting new flight tests with the 1902 glider. Wilbur made the first attempt at powered flight on December 14, but he stalled the aircraft on take-off and damaged the forward section of the machine. Three days were spent making repairs and waiting for the return of good weather. Then, at about 10:35 on the morning of December 17, 1903, Orville made the first successful flight, covering 120 feet (36 metres) through the air in 12 seconds. Wilbur flew 175 feet (53 metres) in 12 seconds on his first attempt, followed by Orville's second effort of 200 feet (60 metres) in 15 seconds. During the fourth and final flight of the day, Wilbur flew 852 feet (259 metres) over the sand in 59 seconds. The four flights were witnessed by five local citizens. For the first time in history, a heavier-thanair machine had demonstrated powered and sustained flight under the complete control of the pilot.



Orville Wright in first controlled flight, 1903Orville Wright beginning the first successful controlled flight in history, at Kill Devil Hills, North Carolina, December 17, 1903. Determined to move from the marginal success of 1903 to a practical airplane, the Wrights in 1904 and 1905 built and flew two more aircraft from Huffman Prairie, a pasture near Dayton. They continued to improve the design of their machine during these years, gaining skill and confidence in the air. By October 1905 the brothers could remain aloft for up to 39 minutes at a time, performing circles and other maneuvers. Then, no longer able to hide the extent of their success from the press, and concerned that the essential features of their machine would be understood and copied by knowledgeable observers, the Wrights decided to cease flying and remain on the ground until their invention was protected by patents and they had negotiated a contract for its sale. (Their most successful machine to that date is described in the entry Wright flyer of 1905.)

SUMMARY OF AVIATION HISTORY

-The myth of Daedalus and Icarus tells the story of a father and a son who used wings to escape from the island of Crete. Icarus has become better-known as the flyer who fell from the sky when the wax that joined his wings was melted by the heat of the sun.

-Leonardo da Vinci was a Renaissance painter, sculptor, architect, inventor, military engineer and draftsman — the epitome of a true Renaissance man. Gifted with a curious mind and a brilliant intellect, da Vinci studied the laws of science and nature, which greatly informed his work. His drawings, paintings and other works have influenced countless artists and engineers over the centuries

-The Montgolfier hot-air balloon floats over Paris on November 21, 1783. For the first time in history, a human being is lifted and carried through the air for a sustained period.

- A red-letter date in the progress of aeronautics is 1799. In that year, Sir George Cayley in England engraves on a silver disk his concept of a fuselage, a fixed wing, and horizontal and vertical tails. He is the first person to propose separate mechanisms for the generation of lift and propulsion. He is the grandparent of the concept of the modern airplane.

-Otto Lilienthal designs the first fully successful gliders in history. During the period of time 1891 to 1896. he achieves more than 2000 successful glider flights. If he had not been killed in a glider Crash in 1896, Lilienthal might have achieved powered flight before the Wright brothers.

-Samuel Pierpont Langley, secretary of the Smithsonian Institution, achieves the first sustained heavier-than-air, *unmanned,* powered flight in history with his small scale

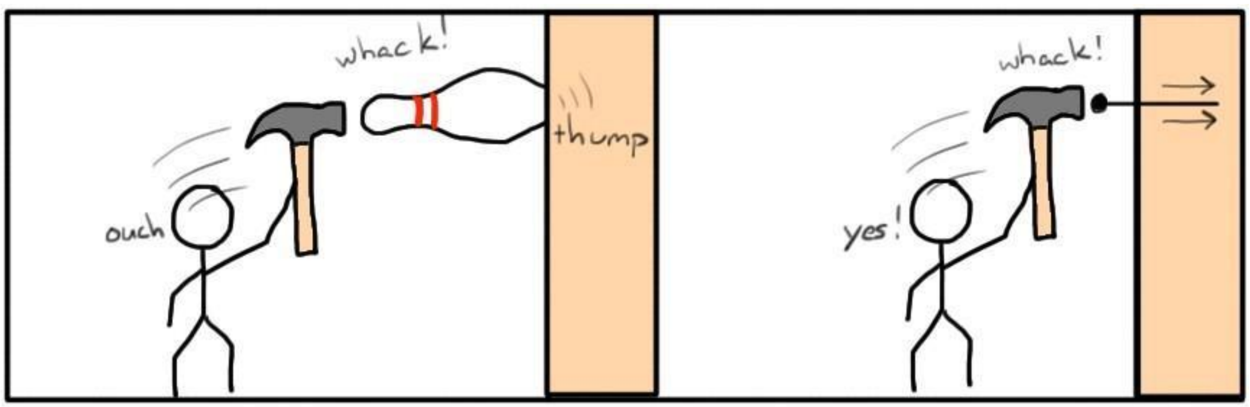
-*Aerodrome* in 1896. However, his attempts at manned flight are unsuccessful, the last one failing on December 8, 1903-just nine days before the Wright brothers' stunning success. Another red-letter date in the history of aeronautics, indeed in the history of humanity, is December 17, 1903. On that day, at Kill Devil Hills in North Carolina, Orville and Wilbur Wright achieve the first controlled, sustained, powered, heavier-than- the air, manned flight in history. This flight is to revolutionize life during the 20 century.

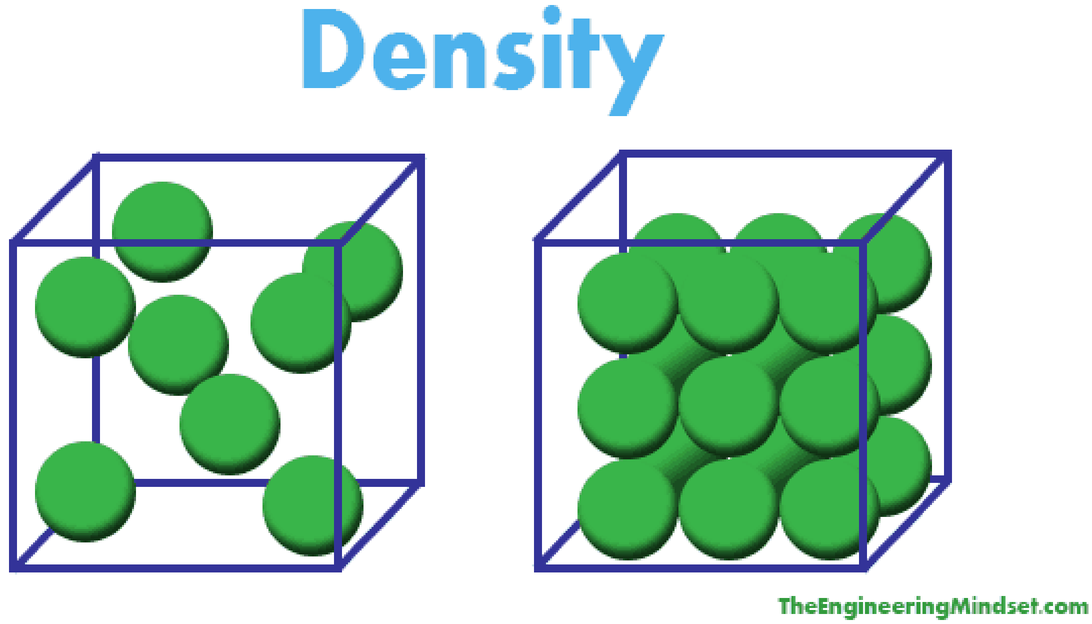
- The development of aeronautics takes off exponentially after the Wright brothers' public demonstrations in Europe and the United States in 1908. The ongoing work of Glenn Curtiss and the Wrights and the continued influence of Langley's early work form an important aeronautical triangle in the development of aeronautics before World War I.

TOPIC 2

What is pressure?
Pressure is kind of like force, but not quite.

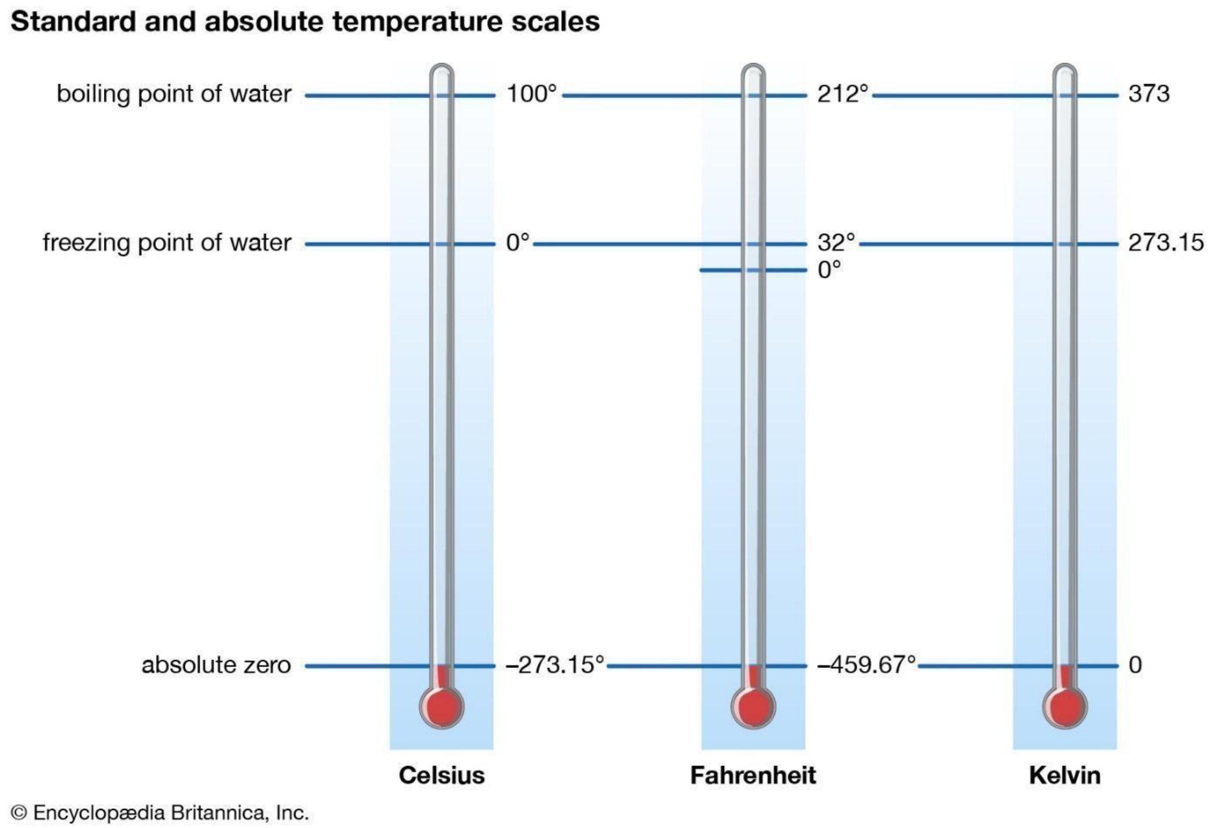
What does pressure mean?
If you tried to hammer a bowling pin into the wall, nothing would probably happen except for people deciding to no longer lend you their bowling pins. However, if you hammer with the same force on a nail, the nail would be a lot more likely to penetrate the wall. This shows that sometimes just knowing the magnitude of the force isn't enough: you also have to know how that force is distributed on the surface of impact. For the nail, all the force between the wall and the nail was concentrated into the very small area on the sharp tip of the nail. However, for the bowling pin the area touching the wall was much larger, and therefore the force was much less concentrated.





Density, mass of a unit volume of a material substance. The formula for density is = *M*/*V*, where *d* is density, *M* is mass, and *V* is volume. Density is commonly expressed in units of grams per cubic centimeter. For example, the density of water is 1 gram per cubic centimeter, and Earth's density is 5.51 grams per cubic centimeter. Density can also be expressed as kilograms per cubic meter (in MKS or SI units). For example, the density of air is 1.2 kilograms per cubic meter. The densities of common solids, liquids, and gases are listed in textbooks and handbooks. Density offers a convenient means of obtaining the mass of a body from its volume or vice versa; the mass is equal to the volume multiplied by the density ($M = Vd$), while the volume is equal to the mass divided by the density ($V = M/d$). The weight of a body, which is usually of more practical interest than its mass, can be obtained by multiplying the mass by the acceleration of gravity. Tables that list the weight per unit volume of substances are also available; this quantity has various titles, such as weight density, specific weight, or unit weight. *See also* specific gravity. The expression *particle density* refers to the number of particles per unit volume, not to the density of a single particle, and it is usually expressed as *n*.

Temperature



Temperature, measure of hotness or coldness expressed in terms of any of several arbitrary scales and indicating the direction in which heat energy will spontaneously flow—i.e., from a hotter body (one at a higher temperature) to a colder body (one at a lower temperature). Temperature is not the equivalent of the energy of a thermodynamic system; e.g., a burning match is at a much higher temperature than an iceberg, but the total heat energy contained in an iceberg is much greater than the energy contained in a match. Temperature, similar to pressure or density, is called an intensive property—one that is independent of the quantity of matter being considered—as distinguished from extensive properties, such as mass or volume.

What Is Velocity in Physics?

Velocity is defined as a vector measurement of the rate and direction of motion. Put simply, velocity is the speed at which something moves in one direction. The speed of a car traveling north on a major freeway and the speed a rocket launching into space can both be measured using velocity.

As you might have guessed, the scalar (absolute value) magnitude of the velocity vector is the speed of motion. In calculus terms, velocity is the first derivative of position with respect to time.

You can calculate velocity by using a simple formula that includes rate, distance, and time.

Velocity Formula

The most common way to calculate the constant velocity of an object moving in a straight line is with this formula: $r = d / t$ r is the rate or speed (sometimes denoted as v for velocity) d is the distance moved t is the time it takes to complete the movement

Units of Velocity

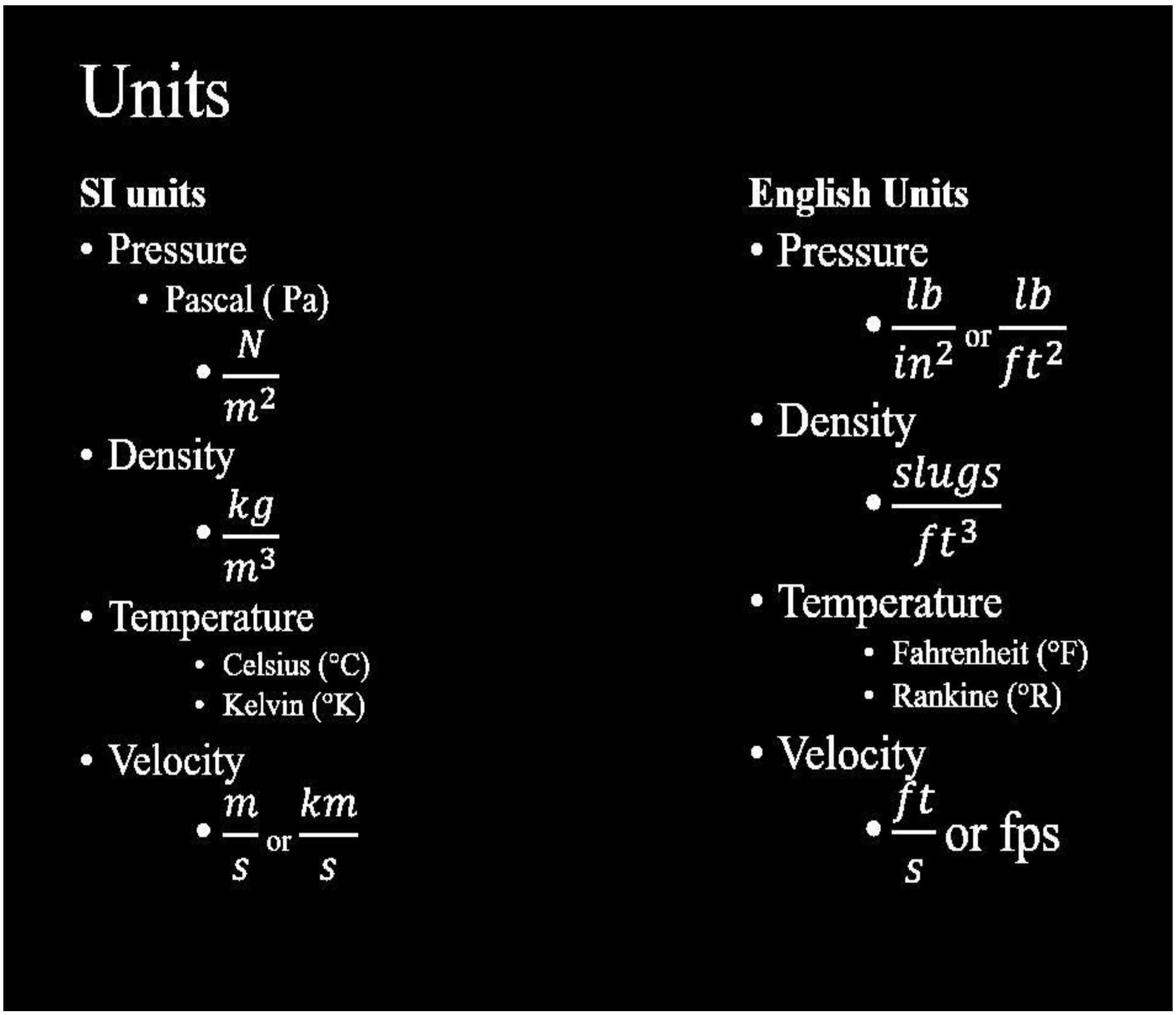
The SI (international) units for velocity are m/s (meters per second), but velocity may also be expressed in any units of distance per time. Other units include miles per hour (mph), kilometers per hour (kph), and kilometers per second (km/s).

Speed, Velocity, and Acceleration

Speed, velocity, and acceleration are all related to each other, though they represent different measurements. Be careful not to confuse these values with each other.

- **Speed**, according to its technical definition, is a scalar quantity that indicates the rate of motion distance per time. Its units are length and time. Put another way, speed is a measure of distance traveled over a certain amount of time. Speed is often described simply as the distance traveled per unit of time. It is how fast an object is moving.

- **Velocity** is a vector quantity that indicates displacement, time, and direction. Unlike speed, velocity measures *displacement,* a vector quantity indicating the difference between an object's final and initial positions. Speed measures distance, a scalar quantity that measures the total length of an object's path.
- **Acceleration** is defined as a vector quantity that indicates the rate of change of velocity. It has dimensions of length and time over time. Acceleration is often referred to as "speeding up", but it really measures changes in velocity. Acceleration can be experienced every day in a vehicle. You step on the accelerator and the car speeds up, increasing its velocity.



APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3

NOTE: Volumes greater than 1000 l shall be shown in m^3.

Symbol	When You Know	Multiply By	To Find	Symbol
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

SUMMARY OF BASIC AIR PROPERTIES

1. Pressure P is the force applied perpendicular to the surface of an object per unit area over which that force is distributed. Various units are used to express pressure. Some of these derive from a unit of force divided by a unit of area; the SI unit of pressure, the pascal (Pa), for example, is one newton per square meter (N/m2); similarly, the pound-force per square inch (psi) is the traditional unit of pressure in the imperial and U.S. customary systems.

2. Pressure may also be expressed in terms of standard atmospheric pressure; the atmosphere (atm) is equal to this pressure, and the torr is defined as 1⁄760 of this. Manometric units such as the centimeter of water, millimeter of mercury, and inch of mercury are used to express pressures in terms of the height of column of a particular fluid in a manometer.

3. The density (more precisely, the volumetric mass density; also known as specific mass), of a substance is its mass per unit volume. The symbol most often used for density is ρ although the Latin letter D can also be used. Mathematically, density is defined as mass divided by volume $\rho = \frac{m}{V}$ where ρ is the density, m is the mass, and V is the volume.

4. Temperature is a physical quantity that expresses hot and cold. It is the manifestation of thermal energy, present in all matter, which is the source of the occurrence of heat, a flow of energy, when a body is in contact with another that is colder.

5. Temperature is measured with a thermometer. Thermometers are calibrated in various temperature scales that historically have used various reference points and thermometric substances for definition. The most common scales are the Celsius scale (formerly called centigrade, denoted °C), the Fahrenheit scale (denoted °F), and the Kelvin scale (denoted K), the last of which is predominantly used for scientific purposes by conventions of the International System of Units (SI).

6. The velocity of an object is the rate of change of its position with respect to a frame of reference, and is a function of time. Velocity is equivalent to a specification of an object's speed and direction of motion. Velocity is a fundamental concept in kinematics, the branch of classical mechanics that describes the motion of bodies.

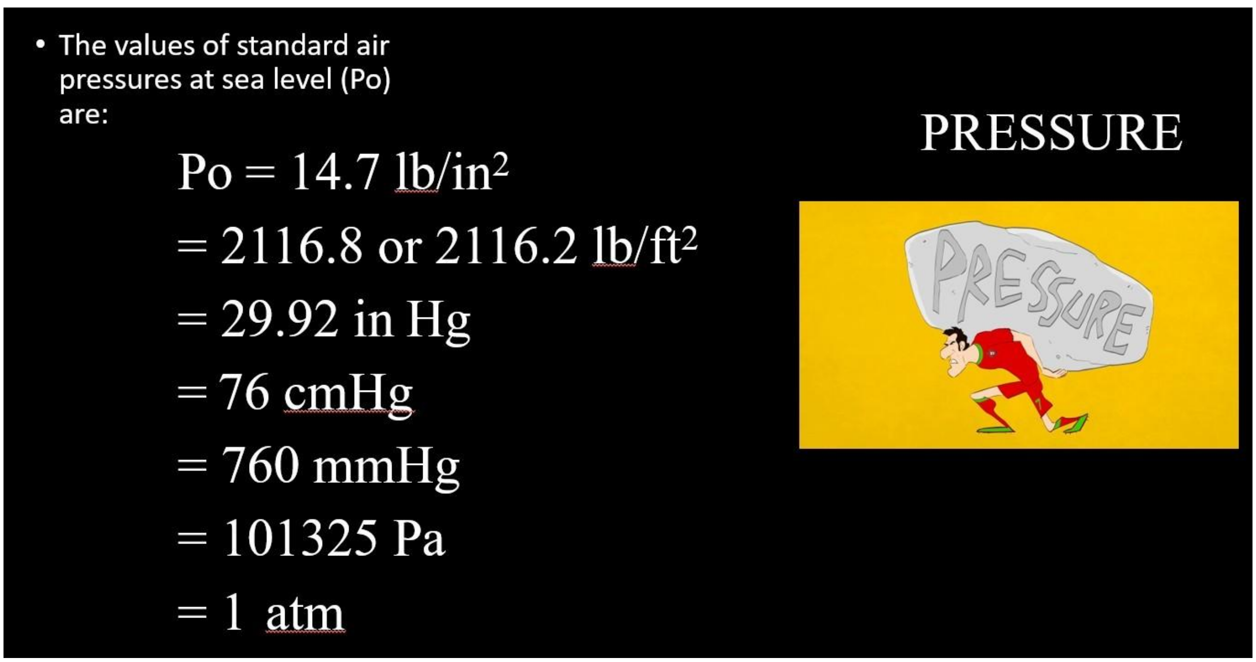
7. Velocity is a physical vector quantity; both magnitude and direction are needed to define it. The scalar absolute value (magnitude) of velocity is called speed, being a coherent derived unit whose quantity is measured in the SI (metric system) as meters per second (m/s) or as the SI base unit of (ms^−1). For example, "5 meters per second" is a scalar, whereas "5 meters per second east" is a vector. If there is a change in speed, direction or both, then the object has a changing velocity and is said to be undergoing an acceleration.

MODULE 3

PROPERTIES OF AIR

PRESSURE

Pressure P is the force applied perpendicular to the surface of an object per unit area over which that force is distributed. Various units are used to express pressure. Some of these derive from a unit of force divided by a unit of area; the SI unit of pressure, the pascal (Pa), for example, is one newton per square meter (N/m2); similarly, the pound-force per square inch (psi) is the traditional unit of pressure in the imperial and U.S. customary systems.



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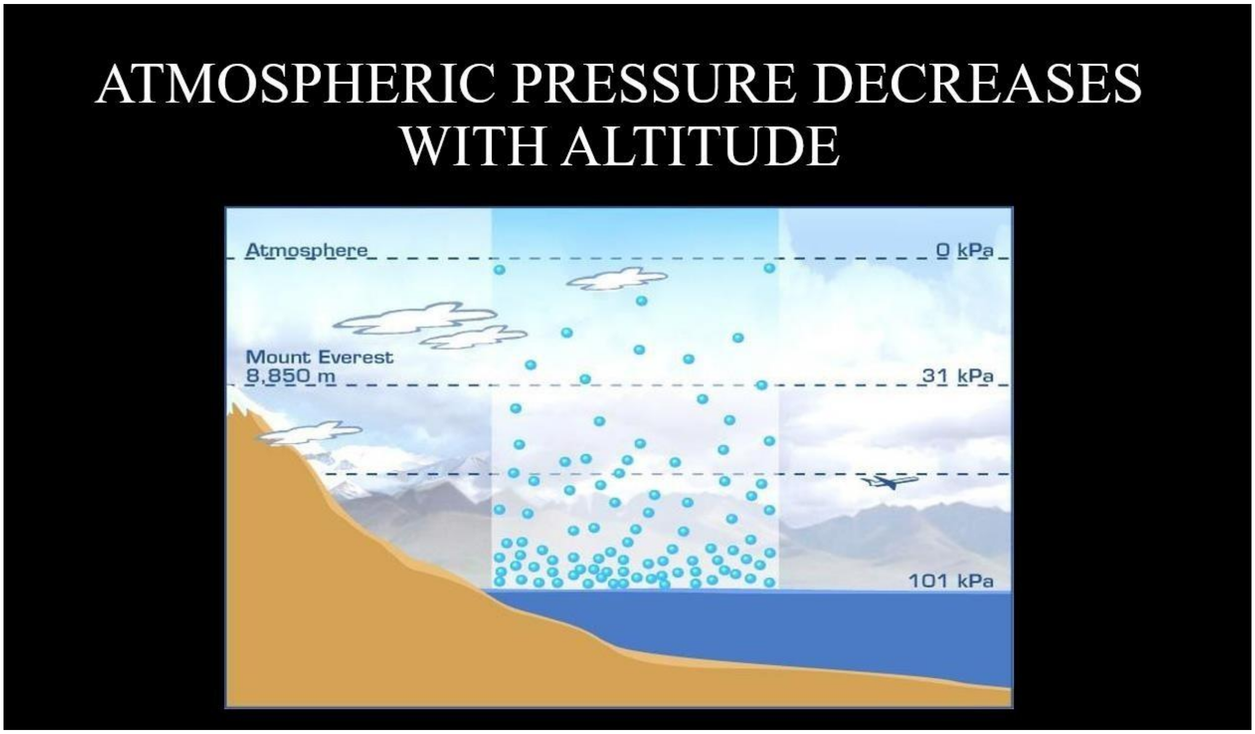
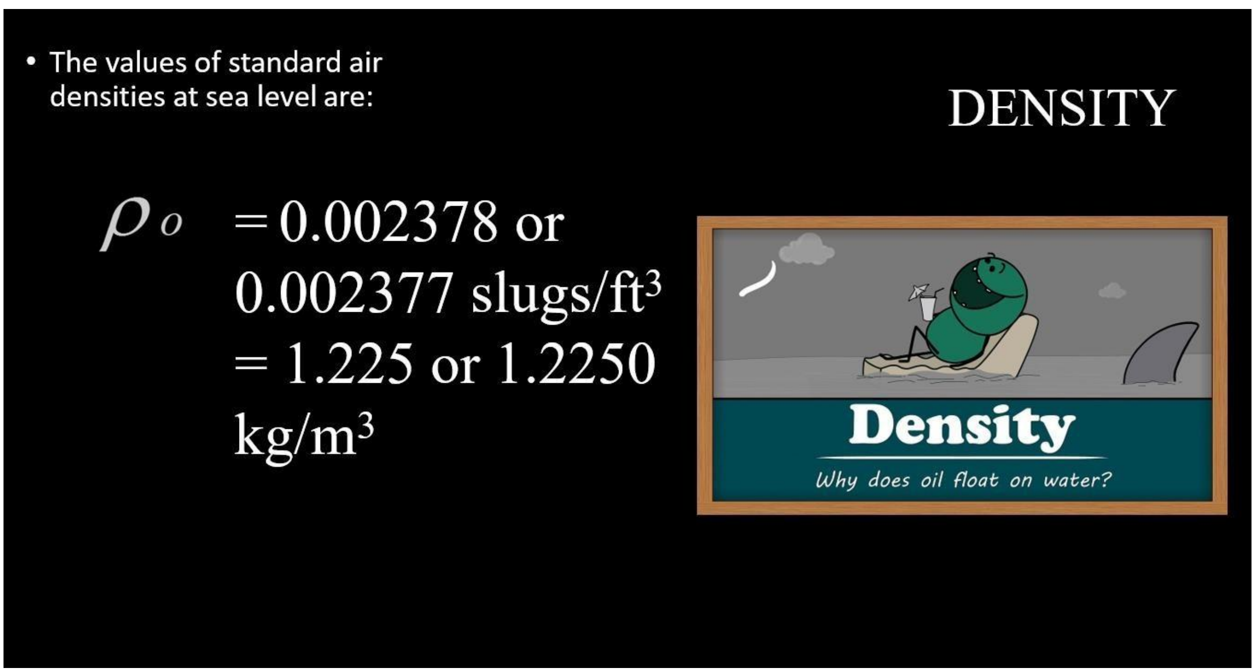


DENSITY



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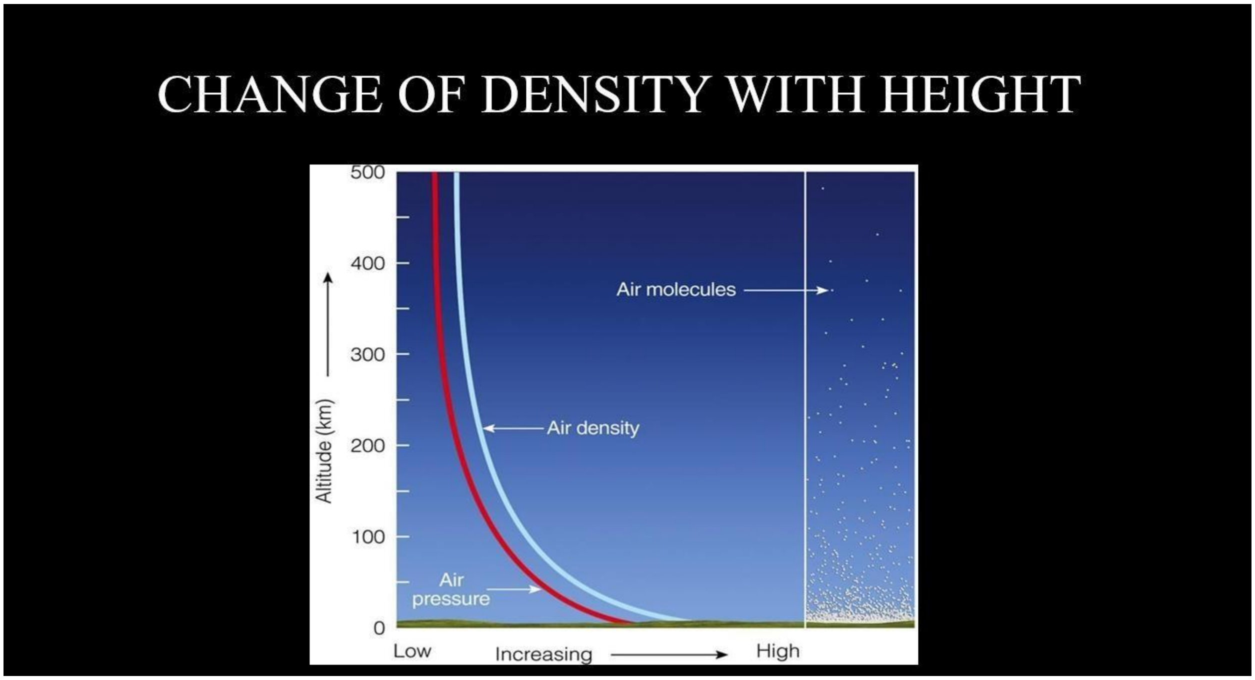
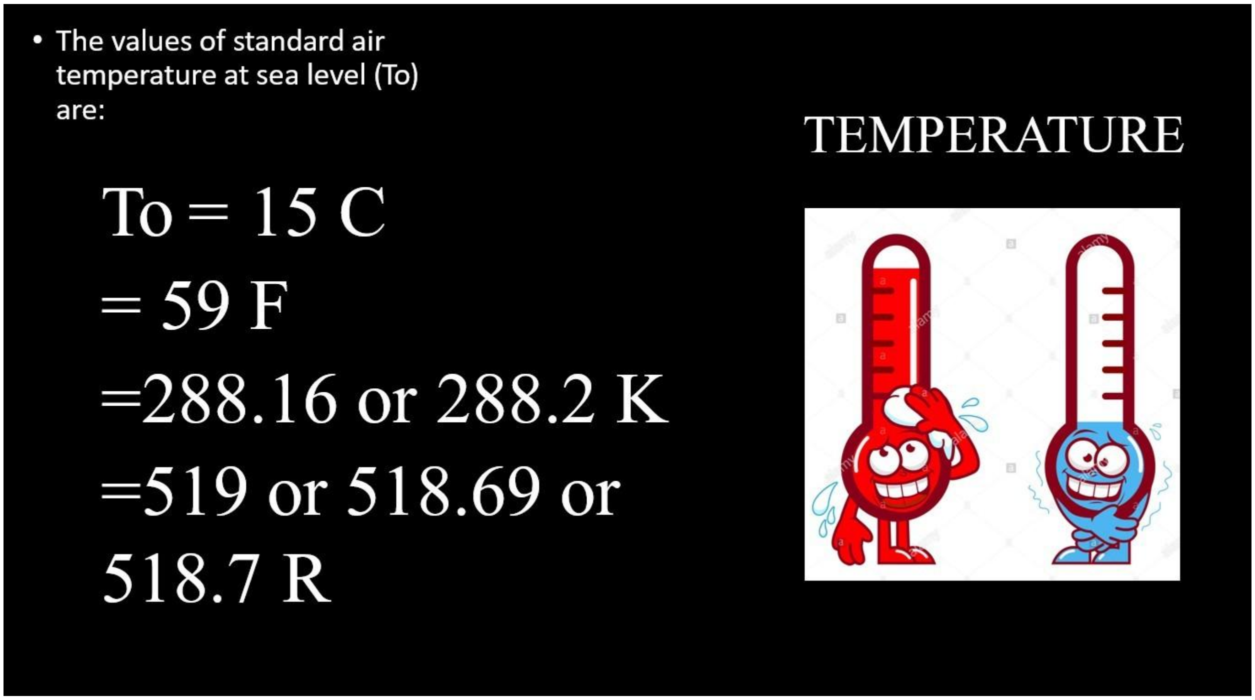
Temperature is a physical quantity that expresses hot and cold. It is the manifestation of thermal energy, present in all matter, which is the source of the occurrence of heat, a flow of energy, when a body is in contact with another that is colder.



TEMPERATURE



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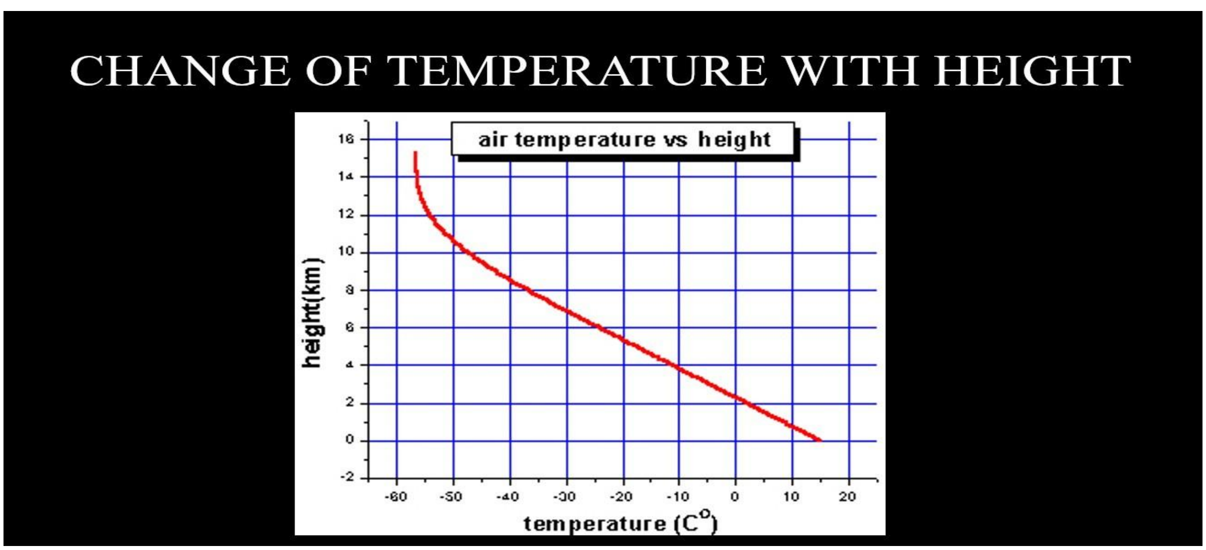


AIR PRESSURE CHANGES WITH ALTITUDE.

Air is all around us, but we cannot see it. Gravity from the Earth pulls air down - this is called air pressure. We don't feel this pressure because our bodies push an equal amount of pressure outward. This graph shows how air density and air pressure changes with altitude (the distance above sea level). Barometers are used to measure air pressure in millibars.

International Standard Atmosphere (ISA)

INTERNATIONAL STANDARD
ATMOSPHERE SEA LEVEL CONDITIONS

	Metric Value	Imperial Value
Pressure	101325Pa	2116.2lb/ft^2
Density	1.225kg/m^3	0.002378slug/ft^3
Temperature	15^{o}C/288.2K	59^{o}F/518.69R
Speed of Sound	340.2m/s	1116.4ft/s
Viscosity	1.789x10^{-5} kg/m/s	3.737x10^{-7} slug/ft/s
Kinematic Viscosity	1.460x10^{-5} m^2/s	1.5723x10^{-4} ft^2/s
Thermal Conductivity	0.02596W/m/K	0.015 BTU/hr/ft/R
Gas Constant	287.1 J/kg/K	1715.7 ft-lbf/slug/R
Specific Heat Cp	1005 J/kg/K	6005 ft-lbf/slug/R
Specific Heat Cv	717.98 J/kg/K	4289 ft-lbf/slug/R
K=Cp/Cv	1.4	
Gravitational Acceleration	9.80665m/s^2	32.174ft/s^2

Description

Also known as the ICAO Standard Atmosphere, ISA is a standard against which to compare the actual atmosphere at any point and time.

The ISA is based the following values of pressure, density, and temperature at mean sea level eachOF which decreases with increase in height:

- Pressure of 1013.2 millibar - Pressure is taken to fall at about 1 millibar per 30 feet in the lower atmosphere (up to about 5,000 feet).
- Temperature of +15 °C - Temperature falls at a rate of 2 °C per 1,000 feet until the tropopause is reached at 36,000 feet above which the temperature is assumed to be constant

  at -57 °C. (The precise numbers are 1.98 °C, -56.5 °C and 36,090 feet)
- Density of 1,225 gm/m3. The real atmosphere differs from ISA in many ways. Sea level pressure varies from day to day, and there are wide extremes of temperature at all levels. Variation in pressure, vertically and horizontally, affects the operation of the pressure altimeter.

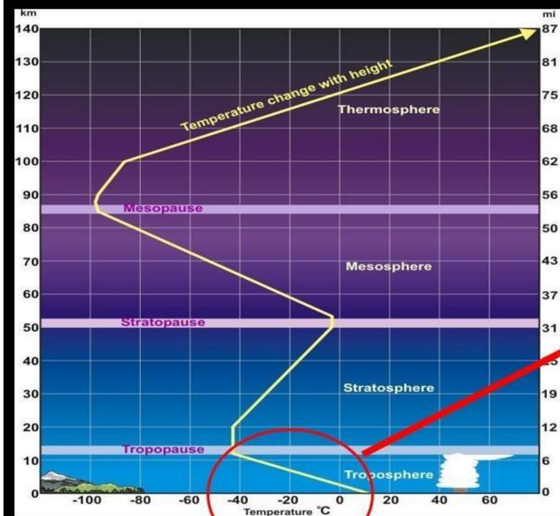
LAPSE RATE

The lapse rate is the rate at which an atmospheric variable, normally temperature in Earth's atmosphere, falls with altitude. Lapse rate arises from the word lapse, in the sense of a gradual

fall.

It corresponds to the vertical component of the spatial gradient of temperature. Although this concept is most often applied to the Earth's troposphere, it can be extended to any gravitationally supported parcel of gas

Variations of Pressure, Temperature, and Density in the Gradient Layers (Troposphere, 0-11 km)



LAPSE RATE

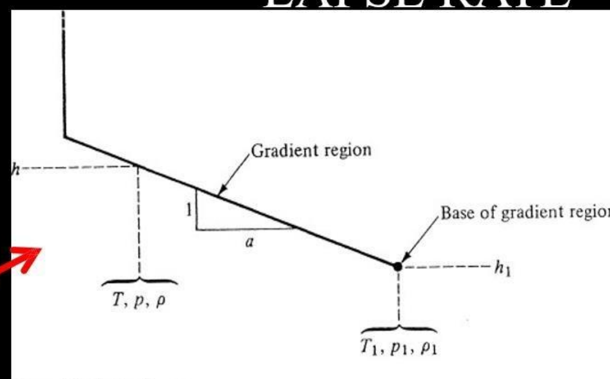


Figure 3.6 Gradient layer.

$$\frac{T - T_1}{h - h_1} = \frac{dT}{dh} = a$$

$$\boxed{a = \frac{dT}{dh}}$$

Temperature Lapse Rate for the Gradient Layers

LAPSE RATE

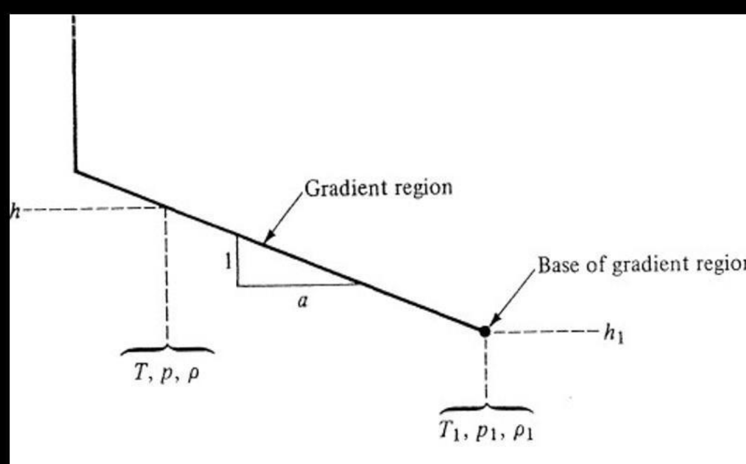


Figure 3.6 Gradient layer.

LAPSE RATE

a = -0.0065 or -0.00651 K/m
-6.5 or -6.51 K/km
-0.003566 R/ft

PRESSURE VARIATION WITH ALTITUDE (TROPOSPHERE 0-11KM)

π

- Consider an Equation

$$dp = -\rho g_0 dh$$

Dividing by the equation of state

$$\frac{dp}{p} = \frac{-\rho g_0 dh}{\rho RT} = -\frac{g_o}{RT} dh$$

BUT $dh = \frac{1}{a} dT$

Substituting the results....

$$\frac{dp}{p} = -\frac{g_0}{aR}\frac{dT}{T} \longrightarrow \int_{P_1}^{P}\frac{dp}{p} = -\frac{g_0}{aR}\int_{T_1}^{T}\frac{dT}{T}$$

$$\ln\frac{P}{P_1} = -\frac{g_o}{aR}\ln\frac{T}{T_1}$$

The General Equation for Pressure Variation with altitude $\longleftarrow$

$$\boxed{\frac{P}{P_1} = \left(\frac{T}{T_1}\right)^{-g_o/(aR)}}$$

SUBSTITUTING FOR METRIC VALUES (SAME RESULTS FOR ENGLISH VALUES)…

$$\frac{-g}{aR} = \frac{-9.81\ m/s^2}{-0.0065\ K/m(287.08\ N.m/kg.K)}$$

$$\boxed{= 5.26}$$

Therefore our equation will be.....

$$\boxed{\frac{P}{P_1} = \left[\frac{T}{T_1}\right]^{5.26}}$$

- Where:
  - P = pressure at any altitude up to 11 km
  - Po = standard pressure at sea level
  - T = temperature at any altitude up to 11km
  - To = standard temperature at sea level

$$\frac{P}{P_o} = \left[\frac{T}{T_o}\right]^{5.26}$$

DENSITY VARIATION WITH ALTITUDE (TROPOSPHERE 0-11KM)

FROM THE EQUATION OF STATE, $\frac{P}{P_1} = \frac{\rho T}{\rho_1 T_1}$

HENCE THE EQUATION BECOMES.....

$$\frac{\rho T}{\rho_1 T_1} = \left(\frac{T}{T_1}\right)^{-g_o/(aR)}$$

$$\frac{\rho}{\rho_1} = \left(\frac{T}{T_1}\right)^{-[g_o/(aR)]-1}$$

$$\boxed{\frac{\rho}{\rho_1} = \left(\frac{T}{T_1}\right)^{-([g_o/(aR)]+1)}} \Rightarrow$$

The General Equation for Density Variation with Altitude

$$\left[\frac{-g}{aR}\right]-1=\left[\frac{-9.81\ m/s^2}{-0.0065\ K/m(287.08\ N.m/kg.K)}\right]-1$$

$$\boxed{=4.26}$$

Therefore our equation will be.....

$$\frac{\rho}{\rho_1}=\left[\frac{T}{T_1}\right]^{4.26}$$

$$\frac{\rho}{\rho_o}=\left[\frac{T}{T_o}\right]^{4.26}$$

Where:

ρ = density at any altitude up to 11 km

ρ_o = standard density at sea level

T = temperature at any altitude up to 11 km

T_o = standard temperature at sea level

TEMPERATURE VARIATION WITH ALTITUDE (TROPOSPHERE 0-11KM)

$$a = \frac{dt}{dh}$$

SOLVING FOR dt:

$$dt = adh$$

$$\int_{To}^{T} dt = a\int_{0}^{h} dh$$

$$[\,T\,]_{To}^{T} = a\,[\,h\,]_{0}^{h}$$

$$T - To = a\,[\,h - 0\,]$$

$$T - To = ah$$

$$\boxed{T = To + ah}$$

Temperature variation with altitude formula

Where:

T = temperature at any altitude up to 11 km (troposphere)
To = 288.2 K or 519 R
h = height from sea level up to 11 km
a = lapse rate

EXAMPLE:

Calculate the pressure and density at 5km.

Temperature where: $T_0 = 288.2$ K

$T = T_0 + a\,h$ $a = -0.0065$

$T = (288.2\text{ K}) + (-0.0065)(5\text{km})$

$T = 288.1675$ K

Pressure where: $P_0 = 101325$ Pa

$P = P_0 \left(\frac{T}{To}\right)^{5.26}$

$P = 101325\ Pa \left(\frac{288.1675\ K}{288.2\ K}\right)^{5.26}$

$P = 101264.912$ Pa

Density where: $\rho_0 = 1.225$ kg/m^3

$\rho = \rho_0 \left(\frac{T}{To}\right)^{4.26}$

$\rho = 1.225\text{ kg/m}^3 \left(\frac{288.1675\ K}{288.2\ K}\right)^{4.26}$

$\rho = 1.224411624$ kg/m^3

Variations of Pressure, Temperature, and Density in the Isothermal Layers (Stratosphere, 11-32 km)

PRESSURE VARIATION WITH ALTITUDE (STRATOSPHERE, 11-32km)

CONSIDER THE HYDROSTATIC EQUATION

$$\frac{dp}{dh} = -\rho g \qquad dp = -\rho g dh$$

Divide this by the equation of state,

$$\frac{dp}{P} = \frac{-\rho g dh}{\rho RT} \Rightarrow \frac{dp}{P} = \frac{-g dh}{RT}$$

PRESSURE VARIATION WITH ALTITUDE (STRATOSPHERE, 11-32km)

$$\int_{P_1}^{P} \frac{dp}{P} = \frac{-g}{RT} \int_{h_1}^{h} dh$$

$$e^{ln \frac{P}{P_1}} = e^{\frac{-g}{RT}(h - h_1)}$$

INTEGRATING, WE HAVE …

$$ln \frac{P}{P_1} = \frac{-g}{RT}(h - h_1)$$

$$\boxed{\frac{P}{P_1} = e^{-\left(\frac{g}{RT}\right)(h - h_1)}}$$

PRESSURE VARIATION WITH ALTITUDE (STRATOSPHERE, 11-32km)

$$\frac{P}{P_1} = e^{-\left(\frac{g}{RT}\right)(h - h_1)}$$

Where:

- P = pressure at any altitude above 11 km
- P_1 = pressure at 11km
- g = gravitational constant, (9,81 m/s², 32.2 ft/s²)
- R = gas constant, for air (287.08 J/kg.K, 53.342 ft.lbf/lbm.R)
- T = constant temperature at stratosphere 216.5 K, 390.15 R
- h = the given altitude above 11,000 m h_1 = 11,000 m

DENSITY VARIATION WITH ALTITUDE (STRATOSPHERE, 11-32km)

$$\frac{P}{P_1} = e^{-\left(\frac{g}{RT}\right)(h - h_1)}$$

$$\frac{\rho}{\rho_1} = e^{-\left(\frac{g}{RT}\right)(h - h_1)}$$

From the equation of state:

$$\frac{P}{P_1} = \frac{\rho RT}{\rho_1 RT_1} = \frac{\rho \cancel{T}}{\rho_1 \cancel{T_1}} = \frac{\rho}{\rho_1}$$

DENSITY VARIATION WITH ALTITUDE (STRATOSPHERE, 11-32km)

$$\frac{\rho}{\rho_1} = e^{-\left(\frac{g}{RT}\right)(h - h_1)}$$

Where:

- ρ = density at any altitude above 11 km
- ρ_1 = density at 11 km
- g = gravitational constant, (9,81 m/s², 32.2 ft/s²)
- R = gas constant, for air (287.08 J/kg.K, 53.342 ft.lbf/lbm.R)
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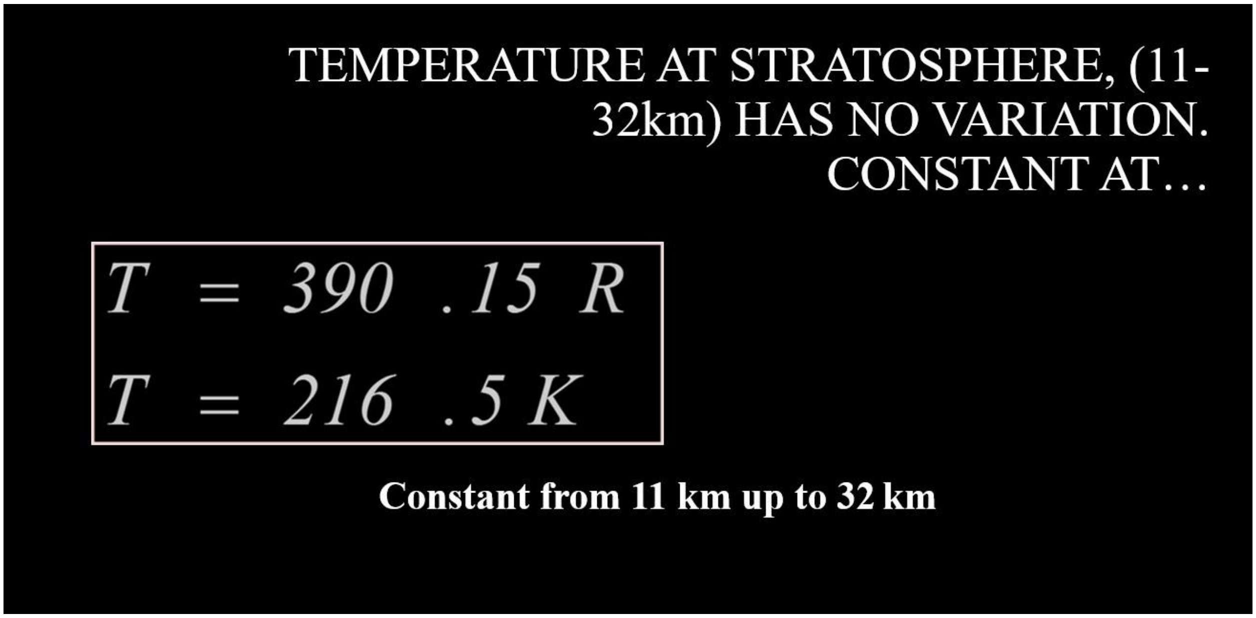
- h = the given altitude above 11,ooo m
- h_1 = 11,000 m



Example

Calculate the pressure and density at altitude 15000km.

Temperature (constant)

T = 216.5 K

Pressure where: P_{11} = 22502.7116 Pa

$P = P_{11}\, e^{(-g / RT)(h - 11000)}$

$P = 22502.7116\ \text{Pa}\ e^{(-9.8 /(287)216.5)(15000-11000)}$

P = 11974. 22627 Pa

Density where: ρ_{11} = 0.3622 kg/m^3

$\rho = \rho_{11}\, e^{(-g / RT)(h - 11000)}$

$\rho = 0.3622\ \text{kg/m}^3\ e^{(-9.8 / (287)216.5)(15000-11000)}$

ρ = 0.192735206 kg/m^3