NATIONAL OPEN UNIVERSITY OF NIGERIA

DEPARTMENT OF PURE AND APPLIED SCIENCE

FACULTY OF SCIENCES

COURSE CODE: PHY 205

COURSE TITLE: INTRODUCTION TO SPACE PHYSICS

COURSE CODE: PHY 205

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COURSE GUIDE

INTRODUCTION

PHY 205 INTRODUCTION TO SPACE PHYSICS is a two-credit unit course available to all students to take towards their B.Sc. Physics, B.Sc. Physics Education and other related programmes in the School of Science.

WHAT YOU WILL LEARN IN THIS COURSE

This course will introduce you to Astronomy and Astrophysics; and how astronomers work. Also, it will give you a clear understanding of the motion of Planets and Kepler's laws of planetary motion. The course will also introduce you to the concepts of satellite communication, Atmospheric Science, Space Environment, Rocket Engineering and Cosmology. It will also expose you to international law and treaties on Space exploration and Development.

COURSE AIMS

The aim of this course is to give you a comprehensive introduction to the principles and concepts of Space Physics; it is also to prepare you towards scientific advancement in atmospheric physics, rocket engineering among others.

COURSE OBJECTIVES

After going through the course, you should be able to:

- Explain what Astronomy is, what it studies and part of the theories and knowledge built around it.
- Describe the constituents of the solar system.
- State the Kepler's laws of planetary motion.
- List the fundamentals of Satellite communication.
- List the basic characteristics of satellites.
- List the advantages of satellite communication.
- Explain the satellite Network Architectures.

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- Explain Meteorology and forecasting in relation to
- Weather and climate.
- State the first law of thermodynamics.
- Understand the space environment.
- Explain the principles of Rocket propulsion.
- Discuss the Evolution of cosmological theories.
- Understand the Space law and Business Development.

WORKING THROUGH THIS COURSE

To complete this course, you are required to read each study unit, read the textbooks and read other materials which may be provided by NOUN.

At certain points in the course you would be required to submit assignments for assessment purposes. At the end of the course, there is a final examination. The course should take you about a total of 12 weeks to complete. Listed below are all the components of the course; what you have to do and how you should allocate your time to each unit in order to complete the course successfully. This course entails that you spend a lot of time to read. We advise that you avail yourself the opportunity of attending the tutorial sessions where you have the opportunity of comparing your knowledge with that of other learners.

COURSE MATERIALS

The following are the major components of this course:

1. The Course Guide
2. Study Units
3. Tutor-Marked Assignments (TMAs)
4. References

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STUDY UNITS

The Study Units in this course are as follows:

Module 1 Introduction to Astronomy and Satellite Communication

Unit1 Introduction to Astronomy

- History of Astronomy
- How Astronomers work

Unit 2 The Solar System

- Our Solar System
- Motion of the Planets

Unit 3 Satellite System

- Fundamentals of Satellite System
- Basic Characteristics of Satellites
- Improved space platforms and launching systems
- Transponder

- Spacecraft and Repeater
- Spacecraft Communications
- Spacecraft Antennas

Unit 4 Satellite Networks

- Satellite orbit configurations
- Satellite Network Architectures
- General features of Satellite Networks

Unit 5 Satellite communications Advantages of Satellite Communication

- The use of Microwave Frequencies
- The Digital Transmission, Compression and Routing
- Cable Television
- Mobile Satellite communications

Module 2 Atmospheric Science & the space Environment

Unit1 Introduction to Atmospheric science

- Scope of Atmospheric Sciences
- Meteorology and Forecasting
- Weather and Climate

Unit 2 Structure of the Atmosphere

- Atmospheric layers and Relation to Temperature
- Global Air circulation and Winds
- Atmospheric Pressure
- Fronts and their Relation to Baroclinic waves

Unit 3 Thermodynamics

- Gas Laws, Equations of State (Ideal Gas law), Boyle's andCharles's law
- First law of Thermodynamics and Specific Heat
- Dry Adiabatic processes and potential temperature

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Unit 4 Atmospheric Dynamics

- Clouds
- Atmospheric kinematics of fluid flow
- Atmospheric Dynamics
- Weather Prediction

Unit 5 The Space Environment

- Where is Space?
- The Solar System
- The Cosmos
- Space environment and Spacecraft

Module 3 Rocket Engineering, Space Exploration & Space Law

Unit1 Rocket Engineering

- Principles of rocket propulsion
- Thermal Rockets

Unit 2 The Rotation of the earth

- Rotation of the earth
- Orbits & spaceflight

Unit 3 introduction to Cosmology

- Fundamental observations of modern cosmology
- Evolution of cosmological theories

Unit 4 Modern Cosmology

- Modern cosmology
- Future of the universe

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Unit 5 Space Law

- International law
- Space treaties

TUTOR-MARKED ASSIGNMENT (TMA)

The TMA is the continuous assessment component of your course. It accounts for 30% of the total score. You will be given at least four TMAs to answer. Three of these must be answered before you are allowed to sit for the end of course examination. The TMAs will be given by your facilitator and you are to return each assignment to your facilitator/tutor after completion. Assignment questions for the units in this course are contained in the assignment file. You will be able to complete your assignment from the information and the material contained in your reading, references and study units. However, it is desirable in all degree levels of education to demonstrate that you have read and researched more into your references, which will give you a wider view point and may provide you with a deeper understanding of the subject. Make sure that each assignment reaches your facilitator/tutor on or before the deadline mentioned by the course coordinator in the presentation schedule and assignment file. If, for any reason, you cannot complete your work on time, contact your facilitator/tutor before the assignment is due to discuss the possibility of an extension. Extensions will not be granted after the due date unless there are exceptional circumstances.

FINAL EXAMINATION AND GRADING

The end of course examination for Introduction to Space Physics will be about two hours and it has a value of 70% of the total course work. The examination will consist of questions which will reflect the self-assessment exercises, practice exercises and tutor-marked assignments you have previously encountered. All areas of the course will be assessed. You are advised to use the time between finishing the last unit and sitting for the examination to revise the entire course. You might find it useful to review your self-assessment exercise, tutor-marked assignments and comments on them before the examination.

COURSE MARKING SCHEME

Assignment Marks	Assignments 1- 4 Four assignments; best three marks of the four
count at 10% each – 30% of the course marks	End of course
Examination	70% of overall course marks
Total 100% of course marks	

MAIN COURSE

CONTENT

Module 1 Introduction to Astronomy and Satellite Communication

Unit1 Introduction to Astronomy

- History of Astronomy
- How Astronomers work

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- Our Solar System
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- Fundamentals of Satellite System
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- Future of the universe

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- International law
- Space treaties

MODULE 1 INTRODUCTION TO ASTRONOMY AND SATELLITE COMMUNICATION

Unit1 Introduction to Astronomy

- History of Astronomy
- How Astronomers work

Unit 2 The Solar System

- Our Solar System
- Motion of the Planets

Unit 3 Satellite System

- Fundamentals of Satellite System
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MODULE 1 INTRODUCTION TO ASTRONOMY AND SATELLITE COMMUNICATION

Unit 1 Introduction to Astronomy

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Unit 3 Satellite System

Unit 4 Satellite Networks

Unit 5 Satellite communications

UNIT1.INTRODUCTION TO ASTRONOMY

CONTENTS

1.0 INTRODUCTION

Astronomy is the study of the universe and the celestial bodies, gas, and dust within it. Astronomy includes observations and theories about the solar system, the stars, the galaxies, and the general structure of space. Astronomy also includes cosmology, the study of the universe and its past and future. People who study astronomy are called astronomers.

2.0OBJECTIVES

At the end of this unit, readers should be able to:

- Understand the meaning of Astronomy and Astrophysics.
- Understand the History and Origin of Astronomy.

- Understand how Astronomers work.
- List and explain the different types of Astronomy.
- Understand the mapping of the Sky.
- Understand that most work in astronomy includes three parts, or phases i.e. Observation, analysis and Comparison of results.
- Explain the various Coordinate systems use by astronomers.
- To define **Right Ascension** and **Declination**.

3.0 MAIN CONTENT

3.1 History of Astronomy

Astronomy is the study of the universe and the celestial bodies, gas, and dust within it. Astronomy includes observations and theories about the solar system, the stars, the galaxies, and the general structure of space. Astronomy also includes cosmology, the study of the universe and its past and future. People who study astronomy are called astronomers, and they use a wide variety of methods to perform their research. These methods usually involve ideas of physics, so most astronomers are also astrophysicists, and the terms *astronomer* and *astrophysicist* are basically identical.

Some areas of astronomy also use techniques of chemistry, geology, and biology. Astronomy is the oldest science, dating back thousands of years to when primitive people noticed objects in the sky overhead and watched the way the objects moved. In ancient Egypt, the first appearance of certain stars each year marked the onset of the seasonal flood, an important event for agriculture. In 17th-century England, astronomy provided methods of keeping track of time that were especially useful for accurate navigation.

Astronomy has a long tradition of practical results, such as our current understanding of the stars, day and night, the seasons, and the phases of the Moon. Much of today's research in astronomy does not address immediate practical problems. Instead, it involves basic research to satisfy our curiosity about the universe and the objects in it. One day such knowledge may well be of practical use to humans. Advances in astronomy over the centuries have depended to a great extent on developments in technology. Initially, ancient peoples could only view the sky with their eyes. With careful attention to the changing positions of the Sun, Moon, planets, and stars, they were able to develop calendars and ultimately predictions of rare events, including eclipses. Instruments that allowed the measurement of the precise positions of celestial objects were the first major technological development, and those measurements formed the basis of models of the solar system. The invention of the telescope in the early 1600s completely changed scientists' ideas about the structure of the solar system and led to the discovery of new planets around our own sun. The telescope was also key to the measurement of distances to nearby stars and thereby provided the first clues to just how vast the universe is. The invention of the spectroscope combined with photography led to the discovery that the stars are made of the same elements found here on Earth (***http://www.cosmosbox.info/Basic_Astronomy_Concepts/History_Astronomy)***.

The great breakthroughs of the 20th century were the development of spacecraft that allowed scientists to observe the universe from outside the distorting effects of Earth's atmosphere, and the development of new sensors capable of detecting other forms of energy our eyes cannot detect. Examples are X-rays, gamma rays, infrared or heat energy, and radio waves. These new windows on the universe have greatly expanded astronomical knowledge. Ancient Babylonian, Assyrian, and Egyptian astronomers all knew the approximate length of the year. The Egyptians of 3,000 years ago adopted a calendar with a year that was 365 days long, very near the modern value of 365.242 days. The Egyptians also used the rising of the star Sirius in the pre-dawn sky to mark the time when the Nile River could be expected to flood.

The Chinese determined the approximate length of the year at about the same time as the Egyptians. The Maya of Central America kept a continuous record of days from day zero, which occurred on our equivalent of August 13, 3114 BC. They also kept track of years, eclipses, and the motions of the visible planets. Their year consisted of 18 months, each 20 days long, plus one 5-day month to total 365 days. Occasional adjustments were made to allow for the extra quarter of a day. The adjustments required in the Maya calendar illustrate a common problem faced by ancient astronomers. Neither an entire month nor an entire year contains an exact whole number of days; to keep calendar years in step with the seasons, which were important for planting crops, the calendar makers assigned different numbers of days to successive months or years. Even though individual months or years were not the same length, they averaged out to approximately the true value. In the British Isles, ancient people used stone circles to keep track of the motions of the Sun and Moon. The best-known example is Stonehenge, a complex array of massive stones, ditches, and holes lay out in concentric circles. Ancient astronomers also observed five bright planets (the ones we call Mercury, Venus, Mars, Jupiter, and Saturn). These bodies, together with the Sun and Moon, move relative to the stars within a narrow band called the zodiac. The Moon moves around the zodiac quickly, overtaking the Sun about once every 29.5 days. The Sun and Moon always move along the zodiac from west to east. The five bright planets—Mercury, Venus, Mars, Jupiter, and Saturn—also have a generally eastward motion against the background of the stars. However, ancient astronomers in many different places around the globe noted that Mars, Jupiter, and Saturn sometimes move westward, in a backwards or retrograde direction. These planets, therefore, appear to have an erratic eastward course, with periodic loops in their paths.

In ancient times, people imagined that celestial events, especially the planetary motions, were connected with their own fortunes. This belief, called astrology, encouraged the development of mathematical schemes for predicting the planetary motions and thus furthered the early progress of astronomy (Bhattacharya, 2013). However, none of the systems of astrology has been shown to be at all effective in making verifiable predictions. Stars provide the background against which the motions of the planets are measured. Ancient Chinese, Egyptians, Greeks, and others gave names to patterns of stars. We call these patterns constellations. Some are very familiar, such as the Big Dipper, the Pleiades, and Orion. Few constellations look like their namesakes. Rather, ancient astronomers probably simply named areas of the sky with prominent groupings of stars after important characters in their mythology.

3.2How Astronomers Work

Professional astronomers usually have access to powerful telescopes, detectors, and computers. Most work in astronomy includes three parts, or phases. Astronomers first observe astronomical objects by guiding telescopes and instruments to collect the appropriate information. Astronomers then analyze the images and data. After the analysis, they compare their results with existing theories to determine whether their observations match with what theories predict, or whether the theories can be improved. Some astronomers work solely on observation and analysis, and some work solely on developing new theories.

Astronomy is such a broad topic that astronomers specialize in one or more parts of the field. For example, the study of the solar system is a different area of specialization than the study of stars. Astronomers who study our galaxy, the Milky Way, often use techniques different from those used by astronomers who study distant galaxies. Many planetary astronomers, such as scientists who study Mars, may have geology backgrounds and not consider themselves as astronomers at all. Solar astronomers use different telescopes than night-time astronomer's use, because the Sun is so bright. Theoretical astronomers may never use telescopes at all. Instead, these astronomers use existing data or sometimes only previous theoretical results to develop and test theories. An increasing field of astronomy is computational astronomy, in which astronomers use computers to simulate astronomical events. Examples of events for which simulations are useful include the formation of the earliest galaxies of the universe or the explosion of a star to make a supernova.

Astronomers learn about astronomical objects by observing the energy they emit. These objects emit energy in the form of electromagnetic radiation. This radiation travels throughout the universe in the form of waves and can range from gamma rays, which have extremely short wavelengths, to visible light, to radio waves, which are very long. The entire range of these different wavelengths makes up the electromagnetic spectrum.

Astronomers gather different wavelengths of electromagnetic radiation depending on the objects that are being studied. The techniques of astronomy are often very different for studying different wavelengths. Conventional telescopes work only for visible light and the parts of the spectrum near visible light, such as the shortest infrared wavelengths and the longest ultraviolet wavelengths. Earth's atmosphere complicates studies by absorbing many wavelengths of the electromagnetic spectrum. Gamma-ray astronomy, X-ray astronomy, infrared astronomy, ultraviolet astronomy, radio astronomy, visible-light astronomy, cosmic-ray astronomy, gravitational-wave astronomy, and neutrino astronomy all use different instruments and techniques.

3.2.1 Optical Astronomy

Until the 20th century, all observational astronomers studied the visible light that astronomical objects emit. Such astronomers are called optical astronomers, because they observe the same part of the electromagnetic spectrum that the human eye sees. Optical astronomers use telescopes and imaging equipment to study light from objects. Professional astronomers today hardly ever actually look through telescopes. Instead, a telescope sends an object's light to a photographic plate or to an electronic light-sensitive computer chip called a charge-coupled device, or CCD. CCDs are about 50 times more sensitive than film, so today's astronomers can record in a minute an image that would have taken about an hour to record on film.

Telescopes may use either lenses or mirrors to gather visible light, permitting direct observation or photographic recording of distant objects. Those that use lenses are called refracting telescopes, since they use the property of refraction, or bending, of light (*see* Optics: Reflection and Refraction). The largest refracting telescope is the 40-in (1-m) telescope at the Yerkes Observatory in Williams Bay, Wisconsin, founded in the late 19th century. Lenses bend different colours of light by different amounts, so different colours focus slightly differently. Images produced by large lenses can be tinged with colour, often limiting the observations to those made through filters. Filters limit the image to one colour of light, so the lens bends all of the light in the image the same amount and makes the image more accurate than an image that includes all colours of light. Also, because light must pass through lenses, lenses can only be supported at the very edges. Large, heavy lenses are so thick that all the large telescopes in current use are made with other techniques.

Gamma-Ray and X-Ray Astronomy

Gamma rays have the shortest wavelengths. Special telescopes in orbit around Earth, such as the National Aeronautics and Space Administration's (NASA's) Compton Gamma-Ray Observatory, gather gamma rays before Earth's atmosphere absorbs them. X rays, the next shortest wavelengths, also must be observed from space. NASA's Chandra X-Ray Observatory (CXO) is a school-bus-sized spacecraft that began studying X-rays from orbit in 1999.

Ultraviolet Astronomy

Ultraviolet light has wavelengths longer than X rays, but shorter than visible light. Ultraviolet telescopes are similar to visible-light telescopes in the way they gather light, but the atmosphere blocks most ultraviolet radiation. Most ultraviolet observations, therefore, must also take place in space. Most of the instruments on the Hubble Space Telescope (HST) are sensitive to ultraviolet radiation (*see* Ultraviolet Astronomy). Humans cannot see ultraviolet radiation, but astronomers can create visual images from ultraviolet light by assigning particular colours or shades to different intensities of radiation.

Infrared Astronomy

Infrared astronomers study parts of the infrared spectrum, which consists of electromagnetic waves with wavelengths ranging from just longer than visible light to 1,000 times longer than visible light. Earth's atmosphere absorbs infrared radiation, so astronomers must collect infrared radiation from places where the atmosphere is very thin, or from above the atmosphere. Observatories for these wavelengths are located on certain high mountaintops or in space. Most infrared wavelengths can be observed only from space. Every warm object emits some infrared radiation. Infrared astronomy is useful because objects that are not hot enough to emit visible or ultraviolet radiation may still emit infrared radiation. Infrared radiation also passes through interstellar and intergalactic gas and dust more easily than radiation with shorter wavelengths. Further, the brightest part of the spectrum from the farthest galaxies in the universe is shifted into the infrared.

Radio Astronomy

Radio waves have the longest wavelengths. Radio astronomers use giant dish antennas to collect and focus signals in the radio part of the spectrum. These celestial radio signals, often from hot bodies in space or from objects with strong magnetic fields, come through Earth's atmosphere to the ground. Radio waves penetrate dust clouds, allowing astronomers to see into the centre of our galaxy and into the cocoons of dust that surround forming stars.

Mapping the Sky

Humans have picked out landmarks in the sky and mapped the heavens for thousands of years. Maps of the sky helped people navigate, measure time, and track celestial events. Now astronomers methodically map the sky to produce a universal format for the addresses of stars, galaxies, and other objects of interest.

a. The Constellations

Some of the stars in the sky are brighter and more noticeable than others are, and some of these bright stars appear to the eye to be grouped together. Ancient civilizations imagined that groups of stars represented figures in the sky. The oldest known representations of these groups of stars, called constellations, are from ancient Sumer (now Iraq) from about 4000 BC. The constellations recorded by ancient Greeks and Chinese resemble the Sumerian constellations. The northern hemisphere constellations that astronomers recognize today are based on the Greek constellations. Explorers and astronomers developed and recorded the official constellations of the southern hemisphere in the 16th and 17th centuries. The International Astronomical Union (IAU) officially recognizes 88 constellations. The IAU defined the boundaries of each constellation, so the 88 constellations divide the sky without overlapping.

A familiar group of stars in the northern hemisphere is called the Big Dipper. The Big Dipper is actually part of an official constellation—Ursa Major, or the Great Bear. Groups of stars that are not official constellations, such as the Big Dipper, are called asterisms. While the stars in the Big Dipper appear in approximately the same part of the sky, they vary greatly in their distance from Earth. This is true for the stars in all constellations or asterisms—the stars making up the group do not really occur close to each other in space; they merely appear together as seen from Earth. The patterns of the constellations are figments of humans' imagination, and different artists may connect the stars of a constellation in different ways, even when illustrating the same myth.

b. Coordinate Systems

Astronomers use coordinate systems to label the positions of objects in the sky, just as geographers use longitude and latitude to label the positions of objects on Earth. Astronomers use several different coordinate systems. The two most widely used are the altazimuth system and the equatorial system. The altazimuth system gives an object's coordinates with respect to the sky visible above the observer. The equatorial coordinate system designates an object's location with respect to Earth's entire night sky, or the celestial sphere.

i. Altazimuth System

One of the ways astronomers give the position of a celestial object is by specifying its *altitude* and its *azimuth*. This coordinate system is called the altazimuth system. The altitude of an object is equal to its angle, in degrees, above the horizon. An object at the horizon would have an altitude of 0°, and an object directly overhead would have an altitude of 90°. The azimuth of an object is equal to its angle in the horizontal direction, with north at 0°, east at 90°, south at 180°, and west at 270°. For example, if an astronomer were looking for an object at 23° altitude and 87° azimuth, the astronomer would know to look fairly low in the sky and almost directly east.

As Earth rotates, astronomical objects appear to rise and set, so their altitudes and azimuths are constantly changing. An object's altitude and azimuth also vary according to an observer's location on Earth. Therefore, astronomers almost never use altazimuth coordinates to record an object's position. Instead, astronomers with altazimuth telescopes translate coordinates from equatorial coordinates to find an object. Telescopes that use an altazimuth mounting system may be simple to set up, but they require many calculated movements to keep them pointed at an object as it moves across the sky. These telescopes fell out of use with the development of the equatorial coordinate and mounting system in the early 1800s. However, computers have made the return to popularity possible for altazimuth systems. Altazimuth mounting systems are simple and inexpensive, and—with computers to do the required calculations and control the motor that moves the telescope—they are practical.

ii. The Equatorial System

The equatorial coordinate system is a coordinate system fixed on the sky. In this system, a star keeps the same coordinates no matter what the time is or where the observer is located. The equatorial coordinate system is based on the celestial sphere. The celestial sphere is a giant imaginary globe surrounding Earth. This sphere has north and south celestial poles directly above Earth's North and South poles. It has a celestial equator, directly above Earth's equator. Another important part of the celestial sphere is the line that marks the movement of the Sun with respect to the stars throughout the year. This path is called the ecliptic. Because Earth is tilted with respect to its orbit around the Sun, the ecliptic is not the same as the celestial equator. The ecliptic is tilted 23.5° to the celestial equator and crosses the celestial equator at two points on opposite sides of the celestial sphere. The crossing points are called the vernal (or spring) equinox and the autumnal equinox. The vernal equinox and autumnal equinox mark the beginning of spring and fall, respectively. The points at which the ecliptic and celestial equator are farthest apart are called the summer solstice and the winter solstice, which mark the beginning of summer and winter, respectively.

As Earth rotates on its axis each day, the stars and other distant astronomical objects appear to rise in the eastern part of the sky and set in the west. They seem to travel in circles around Earth's North or South poles. In the equatorial coordinate system, the celestial sphere turns with the stars (but this movement is really caused by the rotation of Earth). The celestial sphere makes one complete rotation every 23 hours 56 minutes, which is four minutes shorter than a day measured by the movement of the Sun. A complete rotation of the celestial sphere is called a sidereal day. Because the sidereal day is slightly shorter than a solar day, the stars that an observer sees from any location on Earth change slightly from night to night. The difference between a sidereal day and a solar day occurs because of Earth's motion around the Sun.

The equivalent of longitude on the celestial sphere is called **right ascension** and the equivalent of latitude is **declination**. Specifying the right ascension of a star is equivalent to measuring the east-west distance from a line called the prime meridian that runs through Greenwich, England, for a place on Earth. Right ascension starts at the vernal equinox. Longitude on Earth is given in degrees, but right ascension is given in units of time—hours, minutes, and seconds. This is because the celestial equator is divided into 24 equal parts—each called an hour of right ascension instead of 15°. Each hour is made up of 60 minutes, each of which is equal to 60 seconds. Measuring right ascension in units of time makes determining when will be the best time for observing an object easier for astronomers. A particular line of right ascension will be at its highest point in the sky above a particular place on Earth four minutes earlier each day, so keeping track of the movement of the celestial sphere with an ordinary clock would be complicated. Astronomers have special clocks that keep sidereal time (24 sidereal hours are equal to 23 hours 56 minutes of familiar solar time). Astronomers compare the current sidereal time to the right ascension of the object they wish to view. The object will be highest in the sky when the sidereal time equals the right ascension of the object.

4.0 SELF ASSESSMENT EXERCISE

In mapping the Sky, explain in detail the following
i. Constellations ii. Coordinate Systems

5.0 CONCLUSION

You have learnt in this unit, as way of introducing the course, the basics of Astronomy and how Astronomers work.

6.0 SUMMARY

In this unit, you have learnt that:

- Astronomy is the study of the universe and the celestial bodies, gas, and dust within it.
- Terms *astronomer* and *astrophysicist* are basically identical.
- Astronomy has a long tradition of practical results, such as our current understanding of the stars, day and night, the seasons, and the phases of the Moon.
- Most work in astronomy includes three parts, or phases. Astronomers first observe astronomical objects by guiding telescopes and instruments to collect the appropriate information. Astronomers then analyze the images and data. After the analysis, they compare their results with existing theories to determine whether their observations match with what theories predict, or whether the theories can be improved.
- The techniques of astronomy are often very different for studying different wavelengths. Conventional telescopes work only for visible light and the parts of the spectrum near visible light, such as the shortest infrared wavelengths and the longest ultraviolet wavelengths. Earth's atmosphere complicates studies by absorbing many wavelengths of the electromagnetic

spectrum. Gamma-ray astronomy, X-ray astronomy, infrared astronomy, ultraviolet astronomy, radio astronomy, visible-light astronomy, cosmic-ray astronomy, gravitational-wave astronomy, and neutrino astronomy all use different instruments and techniques.

- Astronomers use coordinate systems to label the positions of objects in the sky, just as geographers use longitude and latitude to label the positions of objects on Earth.
- One of the ways astronomers give the position of a celestial object is by specifying its *altitude* and its *azimuth*. This coordinate system is called the altazimuth system.
- The equivalent of longitude on the celestial sphere is called **right ascension** and the equivalent of latitude is **declination**.

7.0 TUTOR MARKED ASSIGNMENT

1. Write a brief history of the origin of Astronomy.

2. A star is observed to cross the meridian (due south) at an elevation of 34°, as seen from an observatory sited at latitude of 42° north. What is the declination of the star?

3. At the moment of transit, a clock running on Universal Time (UT) read 03 h 16 min 24 s. At the previous midnight, the sidereal time was 14 h 38 min 54 s. Calculate the Right Ascension of the star.

4. Write short notes on the following:

a. Optical Astronomy
b. Gamma-Ray and X-Ray Astronomy
c. Ultraviolet Astronomy
d. Infrared Astronomy
e. Radio Astronomy

8.0 REFERENCES/FURTHER READING

Goldsmith, Donald. *The Astronomers*. New York, NY: Community Television of Southern California, Inc.,1991.

Hartman, William K. *Moon and Planets.* Belmont, CA: Wadsworth, Inc., 1983.

UNIT 2 THE SOLAR SYSTEM

CONTENTS

1.0 INTRODUCTION

Solar System consist of the Sun and everything that orbits the Sun, including the planets and their satellites; the dwarf planets, asteroids, Kuiper belt objects, and comets; and interplanetary dust and gas. The term may also refer to a group of celestial bodies orbiting another star.

2.0 OBECTIVES

At the end of this unit, the reader should be able to:

- Explain the composition of the Solar System.
- Differentiate between comets and Asteroids.
- State and explain the 3 Kepler's laws of planter motion.
- Differentiate between perihelion and aphelion.
- Derive an equation to show the centre of mass.
- Derive the Newton's form of Kepler's 3rd law.

3.0 Our Solar System

Solar systems, both our own and those located around other stars, are a major area of research for astronomers. A solar system consists of a central star orbited by planets or smaller rocky bodies. The gravitational force of the star holds the system together. In our solar system, the central star is the Sun. It holds all the planets, including Earth, in their orbits and provides light and energy necessary for life. Our solar system is just one of many. Astronomers are just beginning to be able to study other solar systems.

- **Planets and their Satellites**

Until the end of the 18th century, humans knew of five planets—Mercury, Venus, Mars, Jupiter, and Saturn—in addition to Earth. When viewed without a telescope, planets appear to be dots of light in the sky. They shine steadily, while stars seem to twinkle. Twinkling results from turbulence in Earth's atmosphere. Stars are so far away that they appear as tiny points of light. A moment of turbulence can change that light for a fraction of a second. Even though they look the same size as stars to unaided human eyes, planets are close enough that they take up more space in the sky than stars do. The disks of planets are big enough to average out variations in light caused by turbulence and therefore do not twinkle.

Between 1781 and 1930, astronomers found three more planets—Uranus, Neptune, and Pluto. This brought the total number of planets in our solar system to nine. However, in 2006 the International Astronomical Union (IAU)—the official body that names objects in the solar system—reclassified Pluto as a dwarf planet. The IAU rulings reduced the number of official planets in the solar system to eight. In order of increasing distance from the Sun, the planets in our solar system are Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune.

Astronomers call the inner planets—Mercury, Venus, Earth, and Mars—the terrestrial planets. Terrestrial (from the Latin word *terra*, meaning “Earth”) planets are Earth-like in that they have solid, rocky surfaces. The next group of planets—Jupiter, Saturn, Uranus, and Neptune—is called the Jovian planets, or the giant planets. The word Jovian has the same Latin root as the word Jupiter. Astronomers call these planets the Jovian planets because they resemble Jupiter in that they are giant, massive planets made almost entirely of gas. The mass of Jupiter, for example, is 318 times the mass of Earth. The Jovian planets have no solid surfaces, although they probably have rocky cores several times more massive than Earth. Rings of chunks of ice and rock surround each of the Jovian planets. The rings around Saturn are the most familiar.

Pluto is tiny, with a mass about one five-hundredth the mass of Earth. Pluto seems out of place, with its tiny, solid body out beyond the giant planets. Many astronomers believe that Pluto is just one of a group of icy objects in the outer solar system. These objects orbit in a part of the solar system called the Kuiper Belt. In 2006 the International Astronomical Union (IAU) reclassified Pluto as a dwarf planet because it had a rounded shape from effects of its own gravity but it was not massive enough to have cleared the region of its orbit of other bodies. Other dwarf planets in the solar system include Eris, an icy body slightly larger than Pluto that also orbits in part of the Kuiper Belt, and Ceres, a rocky body that orbits in the asteroid belt.

Most of the planets have moons, or satellites. Earth’s Moon has a diameter about one-fourth the diameter of Earth. Mars has two tiny chunks of rock, Phobos and Deimos, each only about 10 km (about 6 mi) across. Jupiter has more than 60 satellites. The largest four, known as the Galilean satellites, are Io, Europa, Ganymede, and Callisto.

Ganymede is even larger than the planet Mercury. Saturn has more than 50 satellites. Saturn's largest moon, Titan, is also larger than the planet Mercury and is enshrouded by a thick, opaque, smoggy atmosphere. Uranus has nearly 30 known moons, and Neptune has at least 13 moons. Some of the dwarf planets also have satellites. Pluto has three moons; the largest is called Charon. Charon is more than half as big as Pluto. Eris has a small moon named Dysnomia.

- **Comets and Asteroids**

Comets and asteroids are rocky and icy bodies that are smaller than planets. The distinction between comets, asteroids, and other small bodies in the solar system is a little fuzzy, but generally a comet is icier than an asteroid and has a more elongated orbit. The orbit of a comet takes it close to the Sun, then back into the outer solar system. When comets near the Sun, some of their ice turns from solid material into gas, releasing some of their dust. Comets have long tails of glowing gas and dust when they are near the Sun. Asteroids are rockier bodies and usually have orbits that keep them at always about the same distance from the Sun.

Both comets and asteroids have their origins in the early solar system. While the solar system was forming, many small, rocky objects called planetesimals condensed from the gas and dust of the early solar system. Millions of planetesimals remain in orbit around the Sun. A large spherical cloud of such objects out beyond Pluto forms the Oort cloud. The objects in the Oort cloud are considered comets. When our solar system passes close to another star or drifts closer than usual to the center of our galaxy, the change in gravitational pull may disturb the orbit of one of the icy comets in the Oort cloud. As this comet falls toward the Sun, the ice turns into vapour, freeing dust from the object. The gas and dust form the tail or tails of the comet.

The gravitational pull of large planets such as Jupiter or Saturn may swerve the comet into an orbit closer to the Sun. The time needed for a comet to make a complete orbit around the Sun is called the comet's period. Astronomers believe that comets with periods longer than about 200 years come from the Oort Cloud. Short-period comets, those with periods less than about 200 years, probably come from the Kuiper Belt, a ring of planetesimals beyond Neptune. The material in comets is probably from the very early solar system, so astronomers study comets to find out more about our solar system's formation.

- **The Sun**

The Sun is the nearest star to Earth and is the centre of the solar system. It is only 8 light-minutes away from Earth, meaning light takes only eight minutes to travel from the Sun to Earth. The next nearest star is 4 light-years away, so light from this star, Proxima Centauri (part of the triple star Alpha Centauri), takes four years to reach Earth. The Sun's closeness means that the light and other energy we get from the Sun dominate Earth's environment and life. The Sun also provides a way for astronomers to study stars. They can see details and layers of the Sun that are impossible to see on more distant stars. In addition, the Sun provides a laboratory for studying hot gases held in place by magnetic fields. Scientists would like to create similar conditions (hot gases contained by magnetic fields) on Earth. Creating such environments could be useful for studying basic physics.

The Sun produces its energy by fusing hydrogen into helium in a process called nuclear fusion. In nuclear fusion, two atoms merge to form a heavier atom and release energy. The Sun and stars of similar mass start off with enough hydrogen to shine for about 10 billion years. The Sun is less than halfway through its lifetime.

3.1Motion of Planets

Questions that we will deal with:

1. How do the planets move? Kepler's laws and their physical interpretation

2. How do planetary atmospheres work?

Kepler's laws of planetary motion: Motion of planets governed by three laws:

1. The first law states that each planet moves in an elliptical orbit, with the Sun at one focus of the ellipse.

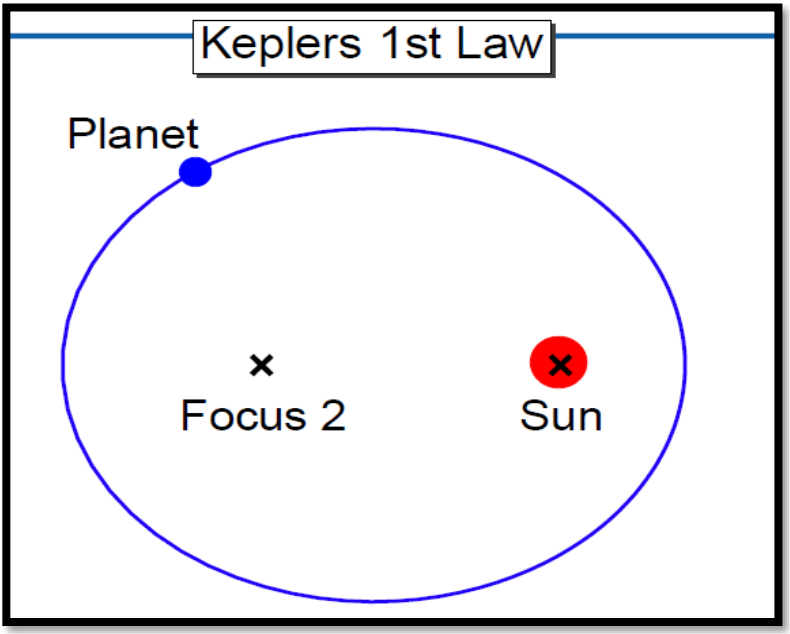


Figure 1. Illustration of the the Kepler's first law

For the planets of the solar system, the ellipses are almost circular, for comets they can be very eccentric.

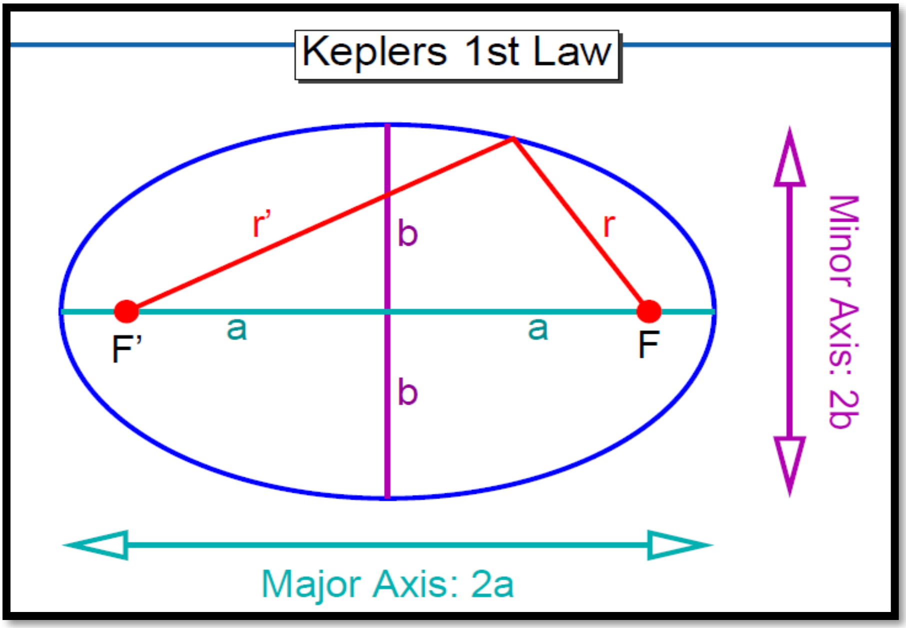
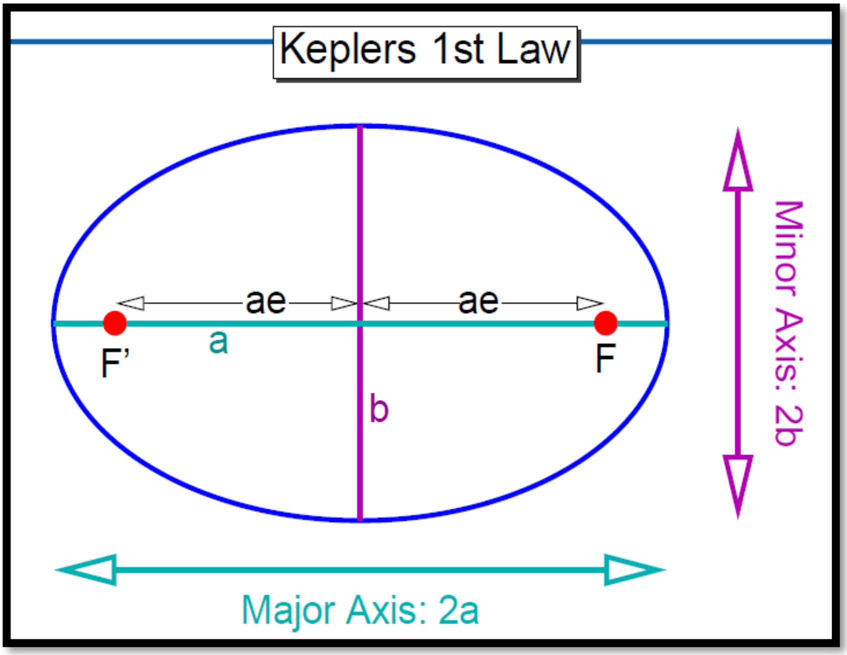


Figure 2.planets of the solar system with ellipses almost circular, Where F and F' are the foci.

Ellipse is equal to the sum of distances r, r' from any point on ellipse to two fixed points (F and F'):

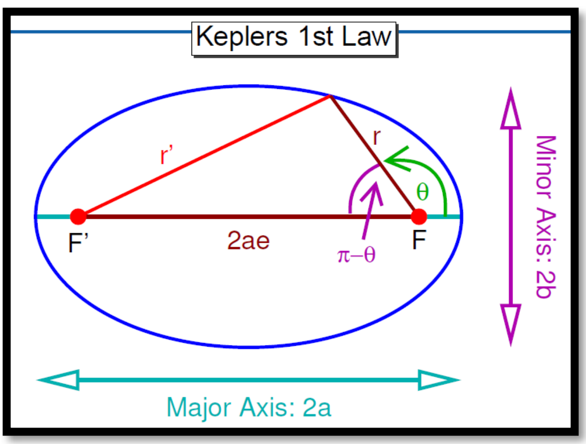
$$\mathbf{r + r' = 2a}$$

Where, a =the semi-major axis of the ellipse.



Eccentricity e: is the ratio between distance from centre of ellipse to focal point and semi-major axis.

Therefore, circles have **e = 0.**



Using the law of cosines:

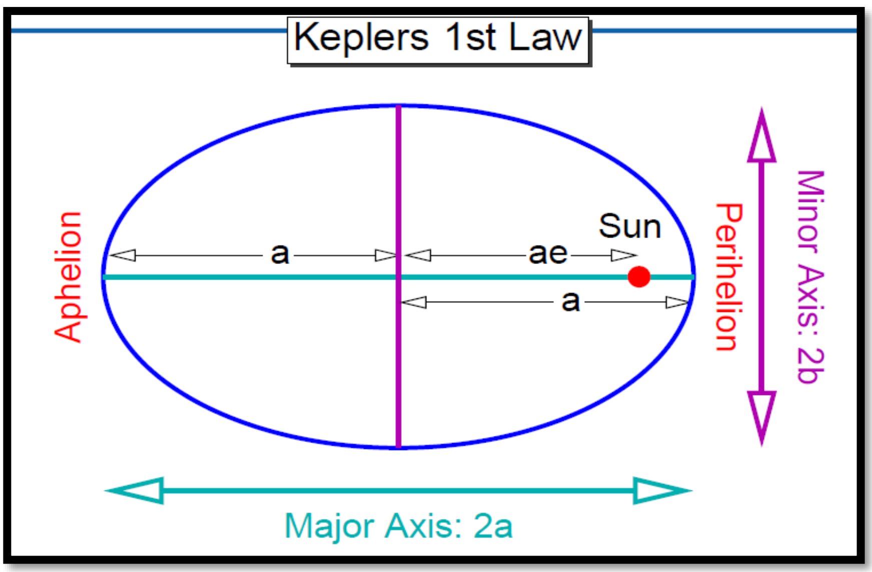
$$r'^2 = r^2 + (2ae)^2 - 2.r.2ae.\cos(\pi-\Theta)$$

Taking **r+ r' = 2a** and solve for r to find the polar coordinate form of the ellipse:

$$r = \frac{a(1-e^2)}{1+e\cos\Theta}$$

You can check this for yourself!

Θ is called the true anomaly.



Finally, we need the closest and farthest point from a focus:

Closest point: **perihelion = a − ae = a(1 − e)**

Farthest point: **aphelion = a + ae = a(1 + e)**

For stars: **periastron** and **apastron,**

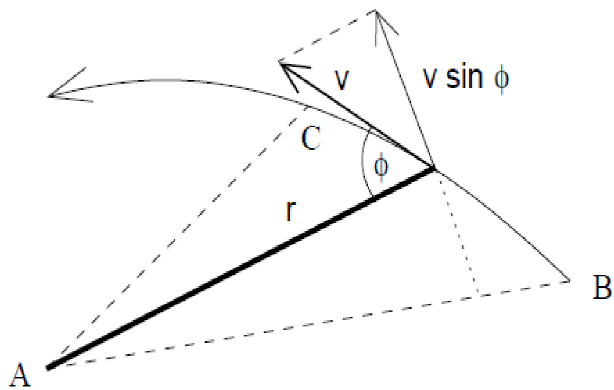
For satellites circling the Earth: **perigee** and **apogee**.

2. The Second law states that a line from the Sun to a given planet sweeps out equal areas in equal times.

   Kepler's 2nd law is a direct consequence of the conservation of angular momentum. Remember that angular momentum is defined as

$$\boldsymbol{L} = \boldsymbol{r} \times \boldsymbol{p} = \boldsymbol{r} \times \boldsymbol{mv}$$

and its absolute value is $\boldsymbol{L} = \boldsymbol{mrv\,sin\emptyset}$



To interpret the angular momentum, look at the figure at the left. Note that v sinϕ is the projection of the velocity vector perpendicular to the radius vector r, and the distance travelled by the planet in an infinitesimally short time Δt is given by Δx = vsinϕΔt. Therefore, the area of the triangle ABC is given by

$$\Delta A = \frac{1}{2} r \Delta x = \frac{1}{2} r \Delta t v sin\emptyset = \frac{L}{2m} \Delta t$$

Kepler's 2nd law states that the "sector velocity" dA/dt is constant with time:

$$\frac{dA}{dt} = \lim_{\Delta t \to 0} \frac{\Delta A}{\Delta t} = \frac{L}{2m} = constant$$

To confirm that this claim is true, we need to prove that

$$\frac{d}{dt}\frac{dA}{dt} = \frac{1}{2m}\frac{dL}{dt} = 0$$

But $\frac{dL}{dt}$ is given by

$$\frac{dL}{dt} = \frac{dr}{dt} \times \bar{P} + \bar{r}\, x\, \frac{d\bar{p}}{dt} = v \times \bar{P} + \bar{r} \times F$$
$$= v \times mv + \bar{r} \times \frac{GMm}{r^2}\frac{\bar{r}}{\bar{r}} = 0$$

Since the cross product of a vector with itself is zero. Therefore, Kepler's 2nd law is true and is a consequence of the conservation of angular momentum for a central field.

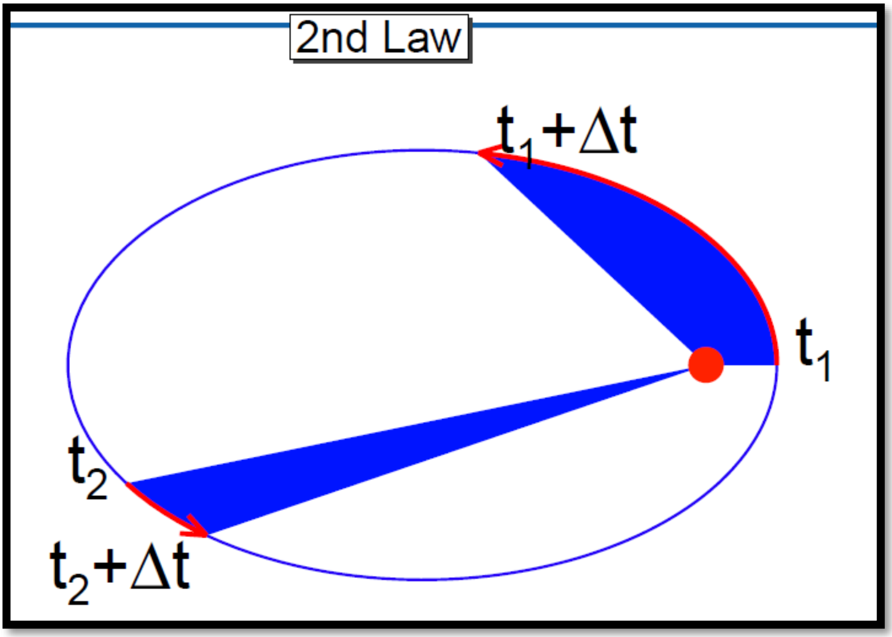


Figure 3. Illustration of the the Kepler's 2nd law

i. Kepler's 2nd Law is also called the *law of Areas*.

ii. perihelion: is a point nearest to the sun in the orbit of a planet → planet is fastest

iii. aphelion: is a point farthest from the sun in the orbit of a planet → planet is slowest

3. The third law states that the square of the orbital periods of the planets is proportional to the cube of the major axes.

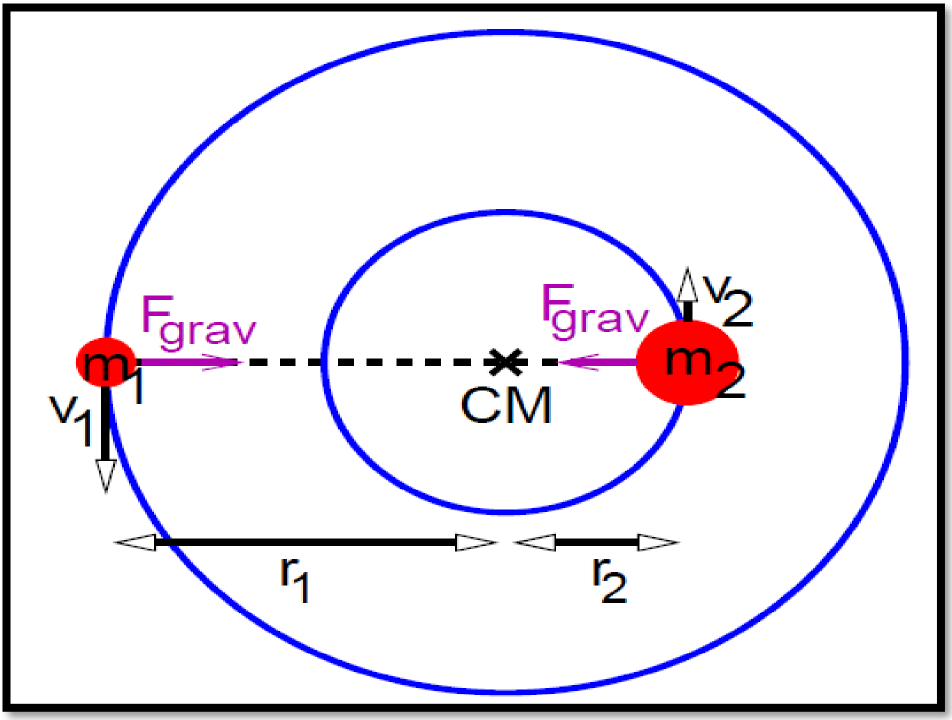
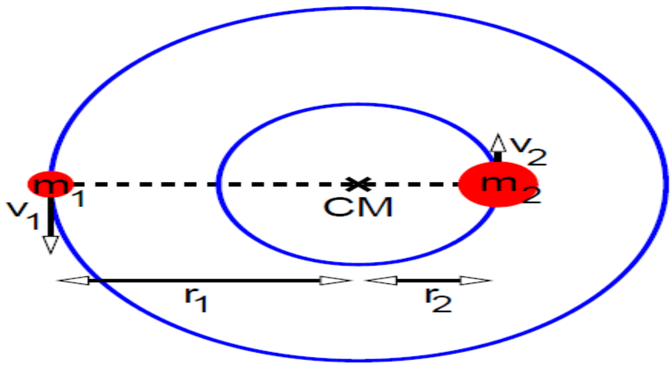


Figure 4. Illustration of the Kepler's 3[rd]law

Computing the motion of two bodies of mass m_1 and m_2 it gives Newton's form of Kepler's third law:

$$P^2 = \frac{4\pi^2}{G(m_1+m_2)} R^3$$

Where $r_1 + r_2 = R$ (for elliptical orbits: R is the semi-major axis).
For an interpretation of Kepler's third law, consider the motion of two bodies with masses $\boldsymbol{m_1}$ and $\boldsymbol{m_2}$ on circular orbits with radii r_1 and r_2 around a point CM (see figure below).



The reason for doing the computation with circular orbits is that the following discussion will be much easier; however, all results from this section also apply to the general case of elliptical motion. The attractive force between the two points is given by Newton's law:

$$F_{grav} = G\frac{m_1 m_2}{R^2} = G\frac{m_1 m_2}{(r_1 + r_2)^2}$$

In order to keep the two bodies on circular orbits, the gravitational force needs to be equal the centripetal force keeping each body on its circular orbit. The centripetal force is

$$F_{1Cent} = \frac{m_1 v_1^2}{r_1} = 4\pi^2 \frac{m_1 r_1}{p^2}$$

$$F_{2Cent} = \frac{m_2 v_2^2}{r_2} = 4\pi^2 \frac{m_2 r_2}{p^2}$$

Let $v = \frac{2\pi r}{p}$ to compute the velocity of each of the bodies. Setting the centripetal force equal to the gravitational force then gives

$$4\pi^2 \frac{m_1 r_1}{p^2} = G\frac{m_1 m_2}{(r_1 + r_2)^2}$$

$$4\pi^2 \frac{m_2 r_2}{p^2} = G\frac{m_1 m_2}{(r_1 + r_2)^2}$$

$$4\pi^2 \frac{r_1}{p^2} = G\frac{m_2}{(r_1 + r_2)^2}$$

$$4\pi^2 \frac{r_2}{p^2} = G\frac{m_1}{(r_1 + r_2)^2}$$

$$\frac{r_1}{r_2} = \frac{m_2}{m_1}$$

$$m_1 r_1 = m_2 r_2$$

This is the definition of the *center of mass*. The total distance between the two bodies is

$$\mathbf{R} = r_1 + r_2 = r_1 + \frac{m_1 r_1}{m_2} = r_1\left(1 + \frac{m_1}{m_2}\right)$$

Inserting into one of the above equations gives

$$\frac{4\pi^2 R}{p^2}\frac{m_2}{m_1 + m_2} = G\frac{m_2}{R^2}$$

Such that

$$\frac{4\pi^2}{p^2} = G\frac{(m_1 + m_2)}{R^3}$$

Or

$$p^2 = \frac{4\pi^2 R^3}{G(m_1 + m_2)}$$

This is *Newton's form of Kepler's 3rd law.*

4.0 SELF ASSESSMENT EXERCISE

Differentiate between Comets and Asteroids from Planets

5.0 CONCLUSION

You have learnt in this unit the meaning and constituents of the Solar system. We also looked at the Kepler's laws of planetary motion and how to derive their mathematical expressions.

6.0 SUMMARY

In this unit, you have learnt that:

- A solar system consists of a central star orbited by planets or smaller rocky bodies.
- In our solar system, the central star is the Sun. It holds all the planets, including Earth, in their orbits and provides light and energy necessary for life.
- In order of increasing distance from the Sun, the planets in our solar system are Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune and Pluto.
- Comets and asteroids are rocky and icy bodies that are smaller than planets. The distinction between comets, asteroids, and other small bodies in the solar system is a little fuzzy, but generally a comet is icier than an asteroid and has a more elongated orbit.
- The first law states that each planet moves in an elliptical orbit, with the Sun at one focus of the ellipse.

- The Second law states that a line from the Sun to a given planet sweeps out equal areas in equal times.
- The third law states that the square of the orbital periods of the planets is proportional to the cube of the major axes.

7.0 TUTOR MARKED ASSIGNMENT

1. State the three Kepler's laws of planetary motion.

2. Derive the Newton's form of Kepler's 3rd law.

3. Differentiate between a Comet and Asteroid

4.What is Eccentricity?

8.0 REFERENCES/FURTHER READING

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UNIT 3 SATELLITE SYSTEMS

CONTENTS

1.0 INTRODUCTION

Satellite systems have evolved into an everyday, commonplace thing. Nearly all television coverage travels by satellite, today reaching directly to the home from space. Even in the age of wideband fibre optic cables and the Internet, satellites still serve the basic telecommunication needs of a majority of countries around the world. For example, domestic satellites have greatly improved the quality of service of the public telephone system and brought nations more tightly together.

2.0 OBJECTIVES

At the end of this unit the reader should be able to:

- Explain the Fundamentals of Satellite Systems.
- List the basic characteristics of satellites.
- Define the term Transponder.

- Discuss the principle of Spacecraft and Repeater.
- List and explain the various types of Spacecraft Antennas.

3.0 MAIN CONTENT

3.1 Fundamentals of Satellite Systems

Satellite communications, no longer a marvel of human space activity, have evolved into an everyday, commonplace thing. Nearly all television coverage travels by satellite, today reaching directly to the home from space. Even in the age of wideband fibre optic cables and the Internet, satellites still serve the basic telecommunication needs of a majority of countries around the world. For example, domestic satellites have greatly improved the quality of service of the public telephone system and brought nations more tightly together. Satellites are adapting to developments in multimedia information and personal communication, with the cost of one-way and two-way Earth stations now within the reach of many potential users. A unique benefit has developed in the area of emergency preparedness and response. When a devastating earthquake hit Mexico City in September 1985, the newly launched Morelos 1 satellite maintained reliable television transmission around the nation even though all terrestrial long-distance lines out of the city fell silent. Similarly, communications were restored to facilitate disaster relief on the island of Sumatra after the December 2004 earthquake and subsequent tsunami.

3.2 Basic Characteristics of Satellites

- A communications satellite is a microwave repeater station that permits two or more users with appropriate earth stations to deliver or exchange information in various forms.

- A satellite in a geostationary Earth orbit (GEO) revolves around the Earth in the plane of the equator once in 24 hours, maintaining precise synchronization with the Earth's rotation.

- There are two other classes of 24-hour orbits: the geosynchronous orbit and the highly elliptical synchronous orbit. Both involve satellites that appear to be stationary relative to a fixed point on the Earth. It is well known that a system of three satellites in GEO each separated by 120 degrees of longitude, as shown in Figure4, can receive and send radio signals over almost all the inhabited portions of the globe. (The small regions around the North and South Poles—above 81° NL and below 81° SL—are not covered.)

- A given GEO satellite has a coverage region, illustrated by the shaded oval, within which Earth stations can communicate with and be linked by the satellite. The range from user to satellite is a minimum of 36,000 km, which makes the design of the microwave link quite stringent in terms of providing adequate received signal power. Also, that distance introduces a propagation delay of about one-quarter of a second for a single hop between a pair of users. The GEO is the ideal case of the entire class of geosynchronous (or synchronous) orbits, which all have a 24-hour period of revolution but are typically inclined with respect to the equator and/or elliptical in shape. As viewed from the Earth, a synchronous satellite in an inclined orbit appears to drift during a day above and below its normal position in the sky. While ideal, the circular GEO is not a stable arrangement, and inclination naturally increases in time. Inclination is controlled by the use of an on board propulsion system with enough fuel for corrections during the entire lifetime of the satellite. A synchronous satellite not intended for GEO operation can be launched with considerably less auxiliary fuel for that purpose. Orbit inclination of greater than 0.1 degree usually is not acceptable for commercial service unless the Earth station antennas can automatically repoint toward (track) the satellite as it appears to move. Mechanical tracking is the most practical (and cumbersome) approach, but electrical beam steering systems are available for specialized applications such as aeronautical mobile. Orbits that are below a mean altitude of about 36,000 km have periods of revolution shorter than 24 hours and hence are termed non-GEO. As illustrated in Figure4 the Iridium

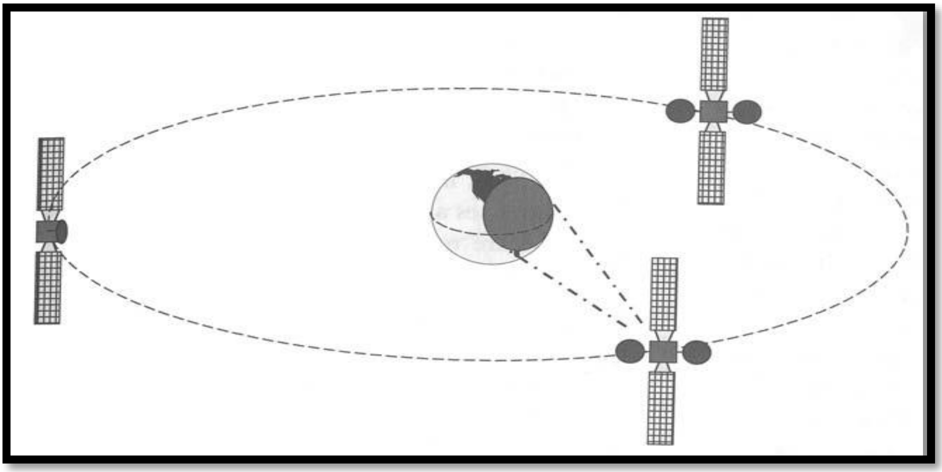

Figure4.A system of three geostationary communication satellites provides nearly worldwide coverage.

system uses multiple satellites to provide continuous coverage of a given region of the Earth. That is simply because the satellites appear to move past a point on the Earth.

- The Iridium mobile satellite system employs low Earth orbit (LEO), in which satellites are at an altitude of approximately 780 km and each passes a given user in only a few minutes. In providing telephone services, users are relatively motionless compared to the satellite they are using. Hence, there is a need to hand off a telephone call while it is in progress.

- The advantage to using a non-GEO satellite network is that the range to the user is shorter; hence, less radiated power is required and the propagation delay is reduced as well. There is considerable complexity and delay in the processing of telephone calls and data communications due to satellite motion and handoffs (Figure 5).

- The key dimension of a GEO satellite is its ability to provide coverage of an entire hemisphere at one time. As shown in Figure6, a large contiguous land area (i.e., a country) as well as offshore locations can simultaneously access a single satellite. If the satellite has a specially designed communications beam focused on those areas, then any receiving antennas within the footprint of the beam (the area of coverage) receives precisely the same transmission. Locations well outside the footprint generally are not able to use the satellite effectively.

- Many satellite networks provide two-way (full-duplex) communications via the same coverage footprint. Terrestrial communications systems, including copper and fibres optic cable and point-to-point microwave radio, offer that capability between fixed points on the ground.

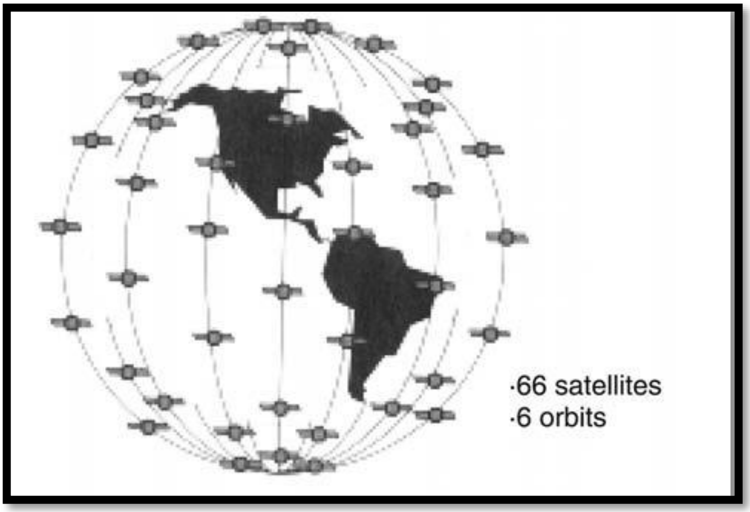

Figure 5.The non-GEO satellite constellation used by the Iridium system (Elbert, 2008).

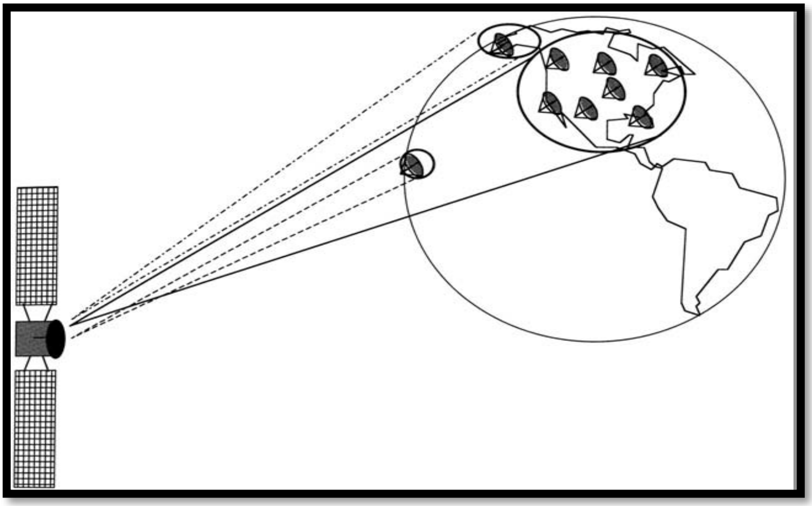

Figure 6.Typical footprint of a U.S. domestic communication satellite showing coverage of continental and offshore points (Elbert, 2008).

- Satellites are designed to last only about 15 years in orbit, because of the practical inability to service a satellite in GEO and replenish consumables (fuel, battery cells, and degraded or failed components). Non-GEO satellites at altitudes below about 1,500 km are subject to atmospheric drag and a harsh radiation environment and are likely to require replacement after 10 years of operation (Figure7).

Figure7.The JCSat 2a satellite operated by SkyPerfect JSAT and built by Boeing. (*Source:* Sky Perfect JSAT.)

3.3 Improved Space Platforms and Launching Systems

Satellites were once relatively small, while the Earth stations that employed them were correspondingly large. Satellite designs used to provide consistent performance, like the dual-spin configuration pioneered by Hughes and the three-axis designs first introduced in Europe by Aerospatiale and Matra and in the United States by RCA Astro and Ford Aerospace.

In time, the three-axis design became the standard of the industry because of its greater capability to lift large communication payloads and to power them at a high level for 15 years or more of service. Those platforms now demonstrate service reliability that is nearly comparable to the previous generation of spinners, although with greater complexity in terms of operational procedure and software requirements. We are now moving into new technologies to further enhance the potential to deliver services that are more useful and economic. Applications like GEO mobile services and two-way multimedia and digital audio broadcasting are pushing the platforms to go beyond what satellites flying in 1998 could deliver. Power levels up to 20 kW and beam pointing down to less than ±0.025 become the norm.

3.4 Transponder

The satellite communication industry has long used the term *transponder* in reference to a defined RF channel of communication within the communication payload. The term itself is a contraction of *transmitter-responder*, originally referring to a single-frequency repeating device found on aircraft. The purpose of the aircraft transponder is to add the identification of the aircraft and actively enhance the power to be reflected back to the radar transmitter. A satellite transponder is entirely different because it is more of a transparent microwave relay channel, also taking into account the need to translate the frequency from the uplink range to the downlink range.

The transponder, then, is a combination of elements within the payload. On the input side, it represents a share of the common uplink and receives equipment within the repeater. We are able to identify specific equipment for each transponder on the downlink side, consisting of the input filter, power amplifier, and output filter. Not shown in the figure are the necessary spare active elements (redundancy) to ensure continuity of service in the event of amplifier or receiver failure. Also not shown at the input to each PA is a level controlling channel amplifier or linearizer often found on modern satellites. The fact that a transponder can be assigned to a particular user application network has caused them to be rented or sold like condominium flats. In actuality, it is the microwave channel of communication bandwidth that the transponder lessor or purchaser acquires.

3.5 Spacecraft and Repeater

The purpose of this unit is to explain how a satellite works and to review the factors in its design. These chapters should familiarize the reader with the key concepts and terminology that are common in the satellite industry. As a first definition, a *spacecraft* is the actual piece of hardware that is launched into orbit to become an artificial *satellite* for the purpose of providing a radio repeater station.

The physical elements that a communications spacecraft comprises can be divided into two major sections: the *communications payload* (or just the payload),containing the actual radio communications equipment used for reception and transmission of radio signals, and the *spacecraft bus* (referred to as the bus), which provides the supporting vehicle to house and operate the payload. The emphasis in this chapter is on the requirements and specifications of the payload and how the general types of hardware designs can meet those requirements.

3.6 Spacecraft Communications

The design, manufacture, and operation of a communications satellite are no simple matter, complicated by the fact that it must survive the rigors of launch and deployment in orbit, followed by many years of satisfactory operation without physical intervention by human beings. In laypersons' terms, we assume that a certified repair person cannot travel to orbit to repair or reconfigure a satellite. That is certainly the case for GEO satellites, but it is not economically feasible even for large constellations of LEO satellites. It is critical that the payload and the bus work hand in hand to establish a highly efficient radio repeater on a stable space platform.

The result is shown in Figure15, which illustrates a typical geostationary communications satellite serving a country or region of a continent. At an altitude of approximately 36,000 km, a beam with dimensions 3 degrees by8 degrees would cover an area the size of the United States. From the standpoint of a typical LEO satellite, the coverage is more limited in area simply because the satellite is much closer to Earth.

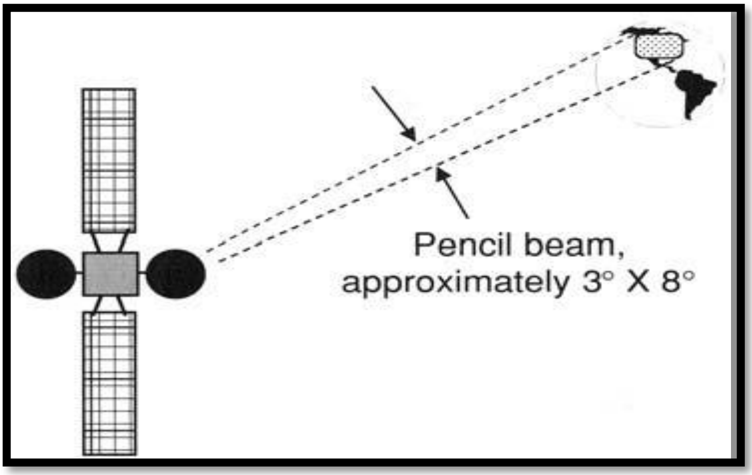

Figure15.Coverage of a land area from GEO requires the generation and control of a pencil beam on board the satellite.

3.7 Spacecraft Antennas

- **Horn Antennas**

Waveguides function in satellite communications as either a component of an antenna or as an antenna in its own right. If we were to take a fixed-length piece of waveguide and use a quarter-wave monopole to drive microwave energy at the proper frequency into one end, the opposite end would radiate some percentage of that power into space. The efficiency of radiation is simply the ratio of the power actually radiated into space divided by the total input power. Power not radiated is reflected back to the transmitter or dissipated as heat within the conducting metal of the waveguide. What this open-ended piece of waveguide has become is the simplest type of on-reflector antenna horn.

Figure16 shows a pyramidal horn in which the end of the waveguide is flared outward in the shape of a pyramid or a cone. The dimensions of the opening are in direct proportion to the wavelength and are dictated by the shaping of the far field antenna pattern. The pyramidal horn is well suited to linear polarized systems because of the natural straightness of extending rectangular waveguide. The standard waveguide mode of propagation is maintained, resulting in a symmetrical main-lobe pattern and little or no cross-polarized component. In contrast, the conical horn flares from either circular or square waveguide (in the latter case, there must be a square-to-circular transition) into a circular aperture. This type of horn is best suited to dual or CP, while the LP performance of the rectangular horn is superior.

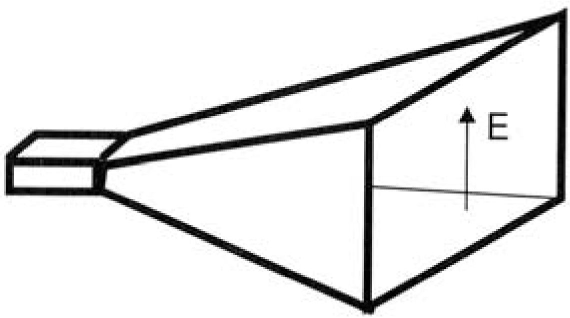

Figure 16.A common type of horn antenna called the pyramidal horn.

The opening is wider than the waveguide to increase gain and to match the impedance of the waveguide (400**Ω**) to free space (377**Ω**).

- **Reflector Antennas**

The simplest and most effective antenna system for a conventional FSS and BSS satellite employs reflectors and feed systems. The feed system normally consists of one or more horn-type radiators. In the transmit mode, microwave energy enters he feed horn from a waveguide that carries the output of the repeater. The feed horn radiates microwave energy from the focus of the parabolic reflector into space in the direction of the reflector (or sub reflector, as the case might be).

Two typical antenna geometries using parabolic reflectors are shown in Figure8. The center-fed parabola is circularly symmetric with the feed located at the focus, while the offset reflector parabola allows the feed to be placed below the line of transmission. The reflector surface is formed by taking a parabola and rotating it about a line drawn from the focus to the center of the parabola (forming a segment of a paraboloid). For the offset case, the required surface is cut from one side of the paraboloid.

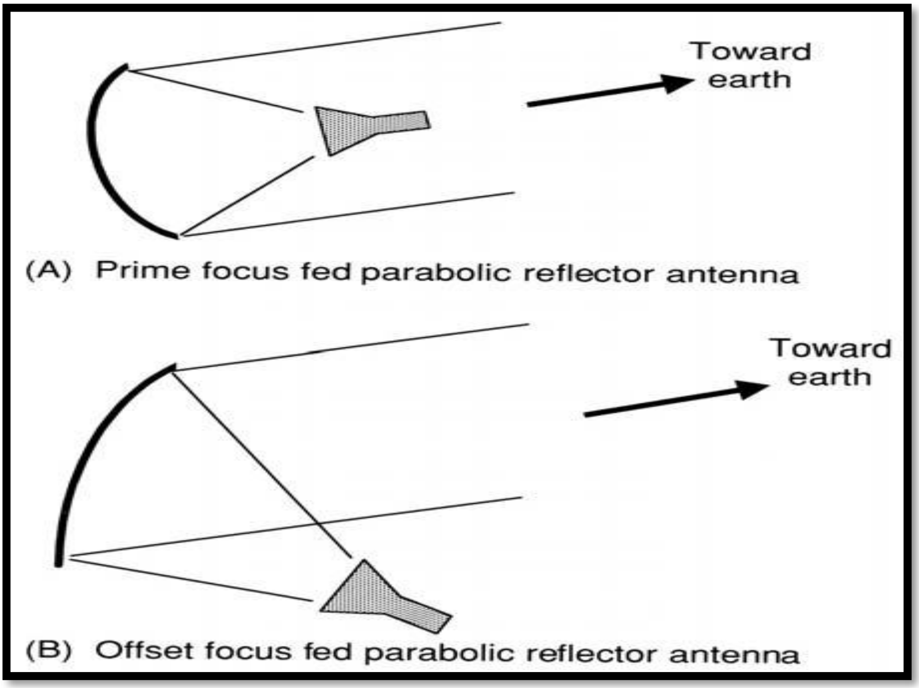

Figure 8. (a) The prime focus-fed parabolic reflector antenna is subject to feed blockage,(b) while the offset feed design provides an unobstructed beam.

4.0 SELF ASSESSMENT EXERCISE

Explain the Basic Characteristics of Satellites.

5.0 CONCLUSION

You have learnt in this unit that a communications satellite is a microwave repeater station that permits two or more users with appropriate earth stations to deliver or exchange information in various forms. That Even in the age of wideband fibre optic cables and the Internet, satellites still serve the basic telecommunication needs of a majority of countries around the world.

6.0 SUMMARY

In this unit, you have learnt that:

- All television coverage travels by satellite, today reaching directly to the home from space.
- A satellite in a geostationary Earth orbit (GEO) revolves around the Earth in the plane of the equator once in 24 hours, maintaining precise synchronization with the Earth's rotation.
- There are two other classes of 24-hour orbits: the geosynchronous orbit and the highly elliptical synchronous orbit.
- Inclination is controlled by the use of an on board propulsion system with enough fuel for corrections during the entire lifetime of the satellite.
- The key dimension of a GEO satellite is its ability to provide coverage of an entire hemisphere at one time.
- The purpose of the aircraft transponder is to add the identification of the aircraft and actively enhance the power to be reflected back to the radar transmitter.
- A spacecraft is the actual piece of hardware that is launched into orbit to become an artificial *satellite* for the purpose of providing a radio repeater station.

7.0 TUTOR MARKED ASSIGNMENT

i. **1.** Discuss the fundamentals of satellite systems.
ii. List five basic characteristics of satellites.
iii. Discuss four advantages of satellite communication.
iv. a. What do you understand by Digital transmission?
b. Define the term Transponder.
v. Describe the principles of the Cable Television.

Vi. An earth station is located at 79:34^{o} W longitude and 37:09^{o} N latitude. Calculate its look angle and range to a geosynchronous satellite whose sub-satellite point is located at 102^{o} W longitude.

vii. Briefly describe the usefulness of an antenna in satellite communication.

viii. Describe how the capacity of a transmission channel can be measured.

8.0 REFERENCES/FURTHER READING

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UNIT4 SATELLITE NETWORKS

CONTENTS

1.0 INTRODUCTION

The majority of satellite operations depend on the reliable transfer of telemetry and command data between the actual Earth stations that are in direct contact with the orbiting satellites and the Control of spacecraft subsystems, where the full range of technical and management functions are performed. Those links, which can employ both terrestrial and satellite networks usually satisfy the data throughput and quality-of-service (QoS) objectives of the overall satellite control system.

2.0 OBJECTIVES

At the end of this unit the reader should be able to:

- Understand the various satellites orbit configurations.
- Explain the architecture of satellite networks.
- List and explain the 3 generic forms of satellite connectivity.
- Define the term Connectivity.

3.0 MAIN CONTENT

3.1 Satellite Orbit Configurations

Having already introduced the concept of GEO and non-GEO satellites, we can now examine some of the technical particulars. Behaviour of a satellite in Earth orbit follows Kepler's laws of planetary motion, which can be restated for artificial satellites as follows:

1. The orbit of each satellite is an ellipse with the Earth centred at one focus.

2. The line joining the satellite and the center of the Earth sweeps out equal areas in equal times. The area is bounded by the arc segment of the orbit and two lines that extend from the centre of the Earth.

3. The square of the period of a satellite is proportional to the cube of its mean distance from the centre of the Earth. That relationship is plotted in Figure9 to give an idea of the relationship between altitude and orbital period.

Lower Earth orbit (LEO) systems employ satellites at altitudes ranging from 500 to 1,000 km. Over that range, the orbit period is between 1.6 and 1.8 hours, the higher orbit resulting in a slightly longer period of revolution. The reason for that small change in period is that it is the distance from the centre of the Earth that determines the period, not the elevation above sea level.

The altitude of a medium Earth orbit (MEO) is around 10,000 km (a period of about 6 hours). Between 2,000 and 8,000 km, there is an inhospitable environment for electronic components produced by the Van Allen radiation belt. The principal advantage of LEO satellites is the shorter range that the radio signal has to traverse, requiring less power and minimizing propagation delay. The range of delay for a single up-down hop is shown at the top of the right-hand graph in Figure 1.8. Their short orbital period produces relatively brief durations when a given satellite can serve a particular user. For altitudes in the range of 8,000 to 10,000 km, a MEO satellite has a much longer period and thus tends to ‘‘hang’’ over a given region on the Earth for a few hours. Transmission distance and propagation delay are greater than for LEO but still significantly less than for GEO. In the case of the latter, there are really two classes of orbits that have a 24-hour period.

A geosynchronous orbit could be elliptical or inclined with respect to the equator (or both). The special case of an equatorial 24-hour circular orbit, in which the satellite appears to remain over a point on the ground (which is on the equator at the same longitude where the satellite is maintained), is called GEO. A 24-hour circular geosynchronous orbit that is inclined with respect to the equator is not GEO because the satellite appears to move relative to the fixed point on the Earth. A GEO satellite would not require ground antennas that track the satellite, while an inclined geosynchronous orbit satellite might. Other non-GEO orbits have been used at various times, such as the highly elliptical Earth orbit (HEO) to allow coverage of northern latitudes (Figure10).

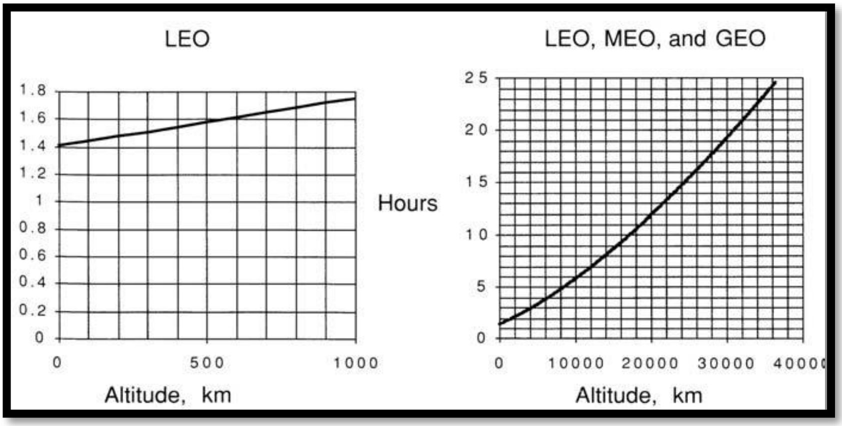

Figure 9. Orbit Period (in hours) versus altitude, based on Kepler's third law.

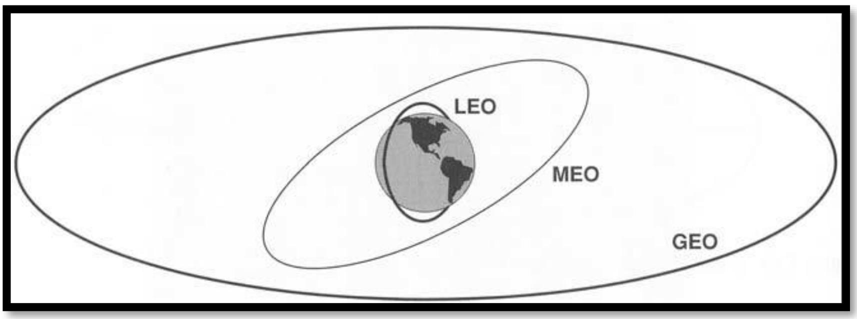

Figure 10. The three most popular orbits for communication satellites are LEO, MEO, and GEO.

The respective altitude ranges are 500 km to 1,000 km for LEO; 5,000 km to 12,000 km for MEO; and 36,000 for GEO. Only one orbit per altitude is illustrated, even though there is a requirement for multiple orbits for LEO and MEO satellites to provide continuous service.

3.2 Satellite Network Architectures

Any communications satellite performs the function of a microwave relay in a telecommunications network. The most basic type of relay is the bent-pipe style of satellite, which does not alter the nature of the transmissions between Earth stations. The Earth stations in this case must organize their transmissions to efficiently use the satellite's repeater resources and to allow the various points on the ground to transfer or exchange the required information that then determines the basic network structure for the particular application. In more advanced repeaters with on board processing, the satellite performs other network functions such as switching the connections between stations or even modifying the format of transmission to further improve the efficiency of transmission. All that is carried out whether there is a single GEO satellite or a constellation of non-GEO satellites serving the network. From the users' perspective, the specific nature of the space segment may be irrelevant. However, the design, operation, and, more important, the required investment, all depend heavily on the way the architecture is put together.

3.3 General Features of Satellite Networks

The property which a satellite network provides via links between users is called *connectivity.* The three generic forms of connectivity are

- point-to-point,
- point-to-multipoint,
- Multi-point interactive.

i. The first uses of satellites were for point-to-point links between fixed pairs of Earth stations. Communication from one station to the other is on a dedicated path over the same satellite. Therefore, two links are needed to allow simultaneous communication in both directions. That is how the typical telephone conversation or interactive data link functions. The link can remain in place for an extended period, called preassigned service, or be put into place for the duration of a conversation, called demand-assigned service. The point-to-point link (Figure11) allowed satellites to create a worldwide network of telephone circuits, providing a solid foundation for international telecommunications development. That was before the days of high-capacity fibre optic cable, a technology that pushed satellites out of this role. Since the 1980s, satellites are used largely for point-to-multipoint connectivity, also called broadcast.

ii. As shown in Figure12, a single uplink station can transmit a continuous stream of information to all receiving points within the coverage area. Satellites like Galaxy 1R in the United States, Astra 1 in Europe, and JCSAT in Japan all use that broadcast mode to transmit television programming to large user populations, thus using the wide-area coverage of a GEO satellite to its greatest extent.

iii. Adding a transmit capability to each receive terminal is a technique to convert the broadcast system into a multipoint interactive network. Each remote site employs a type of Earth station called a very small aperture terminal (VSAT). The broadcast half of the link transmits bulk information to all receiving points. Those points, in turn, can transmit their individual requests or replies back to the originating point over the same satellite. The value of this approach is at its highest when most of the information transfer is from the large Earth station, shown on the left in the figure. For example, a subscriber might request to download an information file containing a software program or short movie, all in digital form. That request is received by the large Earth station, which then transmits the file over the broadcast link. Files and streaming video can be broadcast to many VSATs using the multicast feature of the Internet Protocol. Terrestrial copper and fibre optic cable networks can create all those connectivity, but they do so by stringing point-to-point links together.

iv. Satellite networks, on the other hand, are inherently multipoint in nature and have a decided advantage over terrestrial fixed networks whenever multipoint connectivity is needed. It depends on many variables to determine if this advantage exists in a particular example. A key variable is the capacity of the link, commonly called the *bandwidth*. In digital communication, bandwidth is measured in bits per second (bps). What control those variables are the particular aspects of the telecommunications application that the satellite network delivers. The rest of this section reviews many of those variables, relating them to how they are addressed in a particular satellite network design.

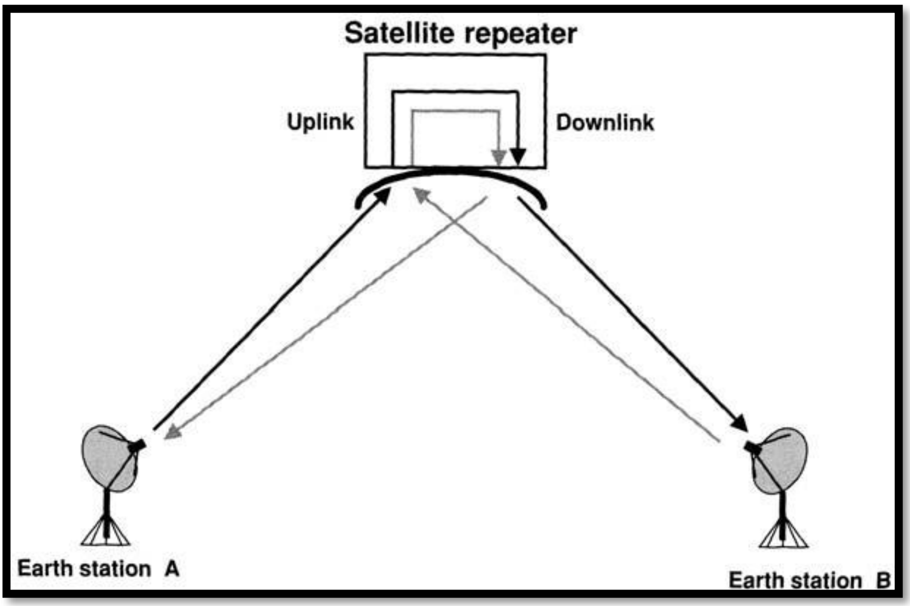

Figure11. The most basic two-way satellite link provides point-to-point connectivity.

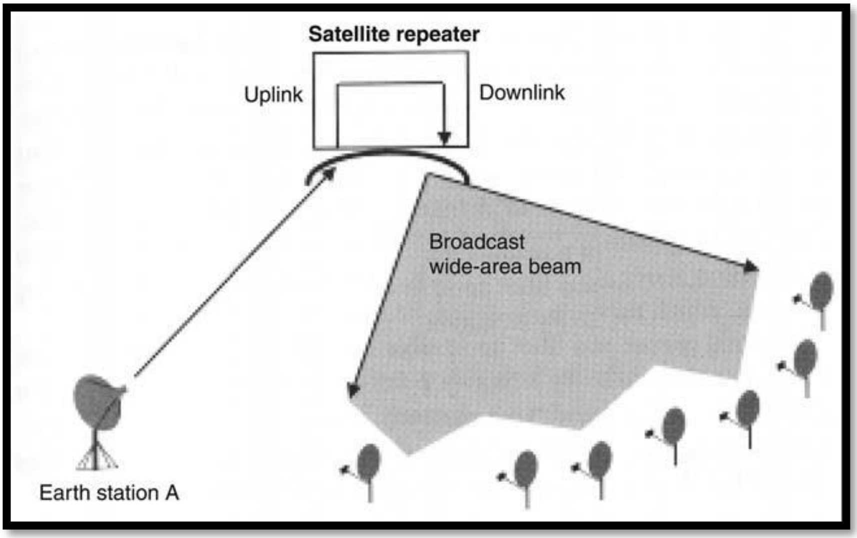

Figure 12. Point-to-multipoint (broadcast) connectivity delivers the same information over the satellite coverage footprint.

4.0 SELF ASSESSMENT EXERCISE

Define the term Connectivity.
List and explain the three generic forms of connectivity.

5.0 CONCLUSION

You have learnt in this unit the various satellites Orbit Configurations, Satellite Network Architectures and General Features of Satellite Networks.

6.0 SUMMARY

In this unit, you have learnt that:

- Behaviour of a satellite in Earth orbit follows Kepler's laws of planetary motion.
- Lower Earth orbit (LEO) systems employ satellites at altitudes ranging from 500 to 1,000 km.
- The altitude of a medium Earth orbit (MEO) is around 10,000 km (a period of about 6 hours).

- The most basic type of relay is the bent-pipe style of satellite, which does not alter the nature of the transmissions between Earth stations.
- The property which a satellite network provides via links between users is called *connectivity.*
- The three generic forms of connectivity are; point-to-point, point-to-multipoint, Multi-point interactive.

7.0 TUTOR MARKED ASSIGNMENT

1. Write short notes on the following:
a. Lower earth orbit (LEO)
b. Medium earth orbit (MEO)
c. Geosynchronous earth orbit (GEO)

2. Briefly explain the following
    - point-to-point,
    - point-to-multipoint,
    - Multi-point interactive.

8.0 REFERENCES/FURTHER READING

Jacoby, C., ‘‘Overview of Systems Engineering,’’ Jacoby Consulting, Long Beach, CA, 2008.

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UNIT5 SATELLITE COMMUNICATIONS

CONTENTS

1.0 INTRODUCTION

This unit identifies the structure and key features of satellite communication and reviews some of the more basic concepts in a nontechnical style. It provides an easy-to-understand overview of the technology and its applications. It begins with the list of the various advantages of satellite communications and moves into the use of Microwave Frequencies.

2.0 OBJECTIVES

At the end of this unit the reader should be able to:

- List the advantages of Satellite Communication.
- List the characteristics of microwave link.
- Understand and discuss the concept of Digital Transmission, Compression and Routing.
- Explain the principle of Cable Television.
- To discuss the three main aspects of the mobile sector.

3.0 MAIN CONTENT

3.1 Advantages of Satellite Communication

- Satellites are used extensively for a variety of communication applications as a result of some well-recognized benefits. These derive from the basic physics of the system, the most important of which is that a satellite can ‘‘see’’ a substantial amount of geography at one time.

- Satellites employ microwave radio signals and thereby benefit from the freedom and mobility of wireless connections. Several advantages are interrelated, while others will become more important as the technology and applications evolve. The point of these benefits is that satellite communication can represent a powerful medium when the developer of the system or service plays to its strengths.

- Satellite TV networks (which deliver programming directly to subscribers by satellite), national department store chains (which use VSAT networks to overcome the limitations of poor or fragmented terrestrial data communication networks), and ocean shipping lines (which demand reliable ship-to-shore communication) depend on satellites as their life's blood. If you can find that kind of connection through satellite technology, then you have a powerful bond on which to build and extend a business or strategic opportunity.

- **Mobile/Wireless Communication, Independent of Location**
  Any users with an appropriate Earth station can employ a satellite as long as they are within its footprint. A properly designed service establishes an effective radio link between the satellite and the user. If that is possible, the radio link is said to ''close.'' The user can be stationary (*fixed* in the terminology) or in motion (i.e., *mobile*). As long as the link closes, the service will be satisfactory for the intended purpose. The phone is oriented so that the back of the modem is pointed toward the satellite position in the equatorial arc.

- **Wide Area Coverage: Country, Continent, or Globe**

While governments control radio services within their borders, the coverage footprint of a satellite does not obey provincial, national, or continental boundaries. When designed properly, a satellite can serve any size region that can see it. As mentioned earlier, a GEO satellite can see about one-third of the Earth's surface. Satellites can be collocated at one orbit position to deliver greater quantities of communication channels, as illustrated for the SES Astra series of satellites (Figure13). A non-GEO constellation like Iridium extends coverage beyond what one satellite sees through a web of inter-satellite links.

- **Wide Bandwidth Available Throughout**

Frequency spectrum availability for satellites is quite good, and satellite users have enjoyed ample bandwidth, principally for fixed services. Bandwidth is the measure of communication capacity in terms of hertz (Hz), either for the amount of radio spectrum used or for the input information that is delivered to the distant end of the link. Most of the satellites in GEO employ microwave frequencies generally between 3.5 and 6.5 GHz (C-band) and between 10.5 and 14.5 GHz (Ku-band). It is common to also refer to the actual transfer rate of user data as bandwidth, although this is really measured in bits per second and not Hz.

- **Independence from Terrestrial Infrastructure**

By providing a repeater station in space, a satellite creates an independent microwave relay for ground-based radio stations. Installing Earth stations directly at the point of application allows users to communicate without external connections. That can be attractive in places where the terrestrial infrastructure is poor or expensive to install or employ. For example, small telephone Earth stations in China extend reliable voice and data services to remote western regions of the country.

- **Rapid Installation of Ground Networks**

Once the satellite (or satellite constellation, in the case of a non-GEO system) is operational, individual Earth stations in the ground segment can be activated quickly in response to demand for services. Each Earth station can be installed and tested in a short time frame, depending on the degree of difficulty associated with the particular site. That is much simpler than for a terrestrial infrastructure, which requires an extensive ground construction program, including securing rights-of-way along cable routes or for towers in the case of microwave or other terrestrial wireless systems.

Maintenance of a ground-based infrastructure also is substantially more expensive and complex, due to the greater quantity of working elements and the opportunities for failure. Satellite communication plays a unique and vital role in restoring basic communications following a disaster. This was illustrated in the United States following the hurricanes of 2005. Installations like that shown in Figure8 can be transported to a disaster site by truck, helicopter, or airplane, and erected in minutes. Normal broadband applications like high-speed Internet, telephone, and video are provided with this type of installation. Satellite communication is often the only way to deliver these services when the existing terrestrial infrastructure is destroyed.

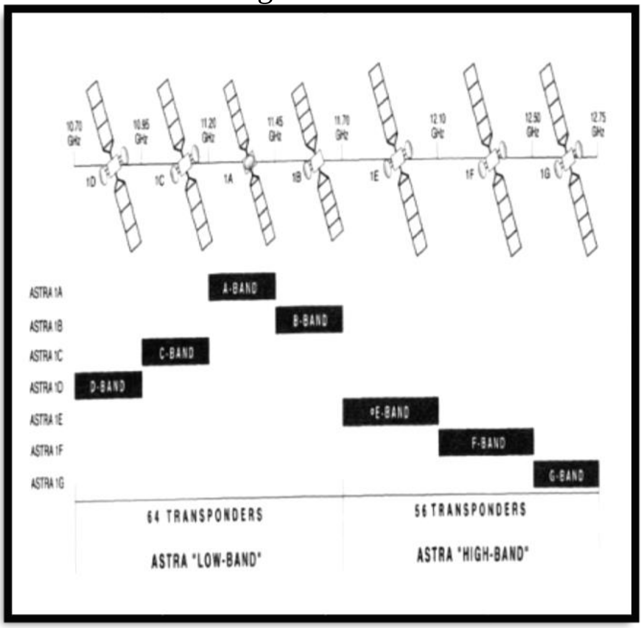

Figure13. Television services are delivered throughout Europe on the SES Astra GEO satellites, operated at 19.2°WL (Elbert, 2008).

3.2 The Use of Microwave Frequencies

Satellites were not the first to employ microwave frequencies, which generally extend from about 1,000 MHz (1 GHz) to 30 GHz. That range was first developed during World War II for radar defence, then applied to various terrestrial communication systems between 1950 and 1980. As a result, the technology base existed at the time that satellite repeaters came into vogue. The microwave link generally is characterized by the following properties:

- Line-of-sight propagation through space and the atmosphere;
- Blockage by dense media, like hills, tree trunks, solid buildings, metal walls, and at higher frequencies, heavy rain;
- Wide bandwidths, compared to the following lower frequency bands: high frequency (HF) shortwave radio, very high

frequency (VHF) TV, frequency modulation (FM) radio, and ultrahigh frequency (UHF) land mobile radio;

- Compact antennas typically using metal reflectors, which can focus energy in a desired direction (thus providing gain over an antenna with broad or omni-directional radiation properties);
- Transmission through metal waveguide structures as opposed to wire conductors;
- Somewhat reduced efficiency of power amplification, which is the ratio of radio frequency (RF) power out divided by the direct current (dc) power in.

3.3 Digital Transmission, Compression and Routing

Digital communication and processing technologies have made a tremendous impact on satellites and their applications. From the time that satellites were introduced commercially in 1965, engineers foresaw the benefits of using digital approaches in lieu of transmitting information in analog form. Through developments in digital cellular systems, computing, image processing, and data communication, the foundation for greater exploitation of satellite networks exists today.

Moore's law of semiconductor technology, which states that there is a doubling of the density of transistors on a chip (and hence the power of computing and capacity for data storage) every 18 months, propels all aspects of information-based high technology. Earth stations that once were housed in buildings were reduced to the size of a clock radio. Such ‘‘smarts’’ now are contained in hand-held units for voice communications. Along with the hardware technology is a body of standards that defines how information can be digitized, compressed down to a small fraction of the number of bits previously demanded, and transferred in effective bundles for a complete end-user service. The most notable is the Motion Picture Experts Group (MPEG) series of standards geared toward television and multimedia.

Other digital standards facilitate voice compression, two-way digital video teleconferencing, and highly interoperable information networks. Notable among terrestrial protocols are the Internet standard, Transmission Control Protocol/Internet Protocol (TCP/IP), and

Asynchronous Transfer Mode (ATM). Satellite networks support those protocols that are the foundation of modern telecommunications.

3.4 Cable Television

The cable television medium has achieved widespread acceptance in major cities around the world, with 70% of North American households subscribing to cable service. Originally a means to bring over-the-air broadcasts into remote areas with otherwise poor reception, a cable TV system uses coaxial and fibre optic cable to connect to each home through a point-to-multipoint distribution network. The arrangement of a typical local cable TV system is shown in Figure 14. The programming material is collected at the head end, which has high-gain receiving antennas to pick up TV signals with reasonably good quality. In fact, the original name for cable TV was CATV, standing for community antenna television. A studio may be provided at a point between the head end and the cable distribution network for playback of commercials, limited program origination and organization of video-on-demand (VOD) services. Unlike over-the-air broadcasting, viewers (called subscribers) pay a monthly fee for reception of the several TV channels delivered by the cable (many of which are ‘‘free’’ advertising supported by local and distant TV stations).

More recently, telephone companies are entering the business using a combination of fibre-to-the-home (FTTH) and Internet Protocol TV (IPTV).

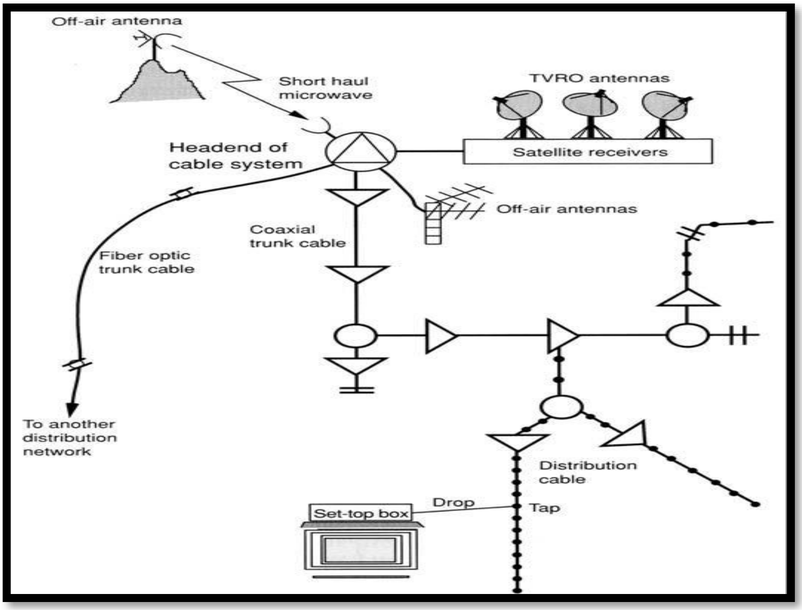

Figure 14.Typical layout of a cable TV system.

3.5Mobile Satellite Communications

The majority of satellite applications discussed up to this point have been to serve fixed points of the ground. While fixed satellite services represent the majority of the commercial business, mobile satellite communications applications have risen to the point of being more than an industry niche. We discuss three main aspects of the mobile sector:

- interactive two-communications using the Mobile Satellite Service (MSS);
- Satellite Digital Audio Radio Service (S-DARS),
- Hybrid system currently under development called ancillary terrestrial component (ATC).

All of these employ the portion of the radio spectrum below **C-band** known as **L-band** and **S-band**. As such, they enjoy somewhat improved propagation in free space as compared to the higher frequencies that are subject to rain attenuation. Complementary portions of L- and S-band are likewise employed by terrestrial wireless services like 3G cellular (EDGE, CDMA 2000, and WCDMA), WiFi (IEEE 802.11x), and WiMAX (IEEE 802.16x).

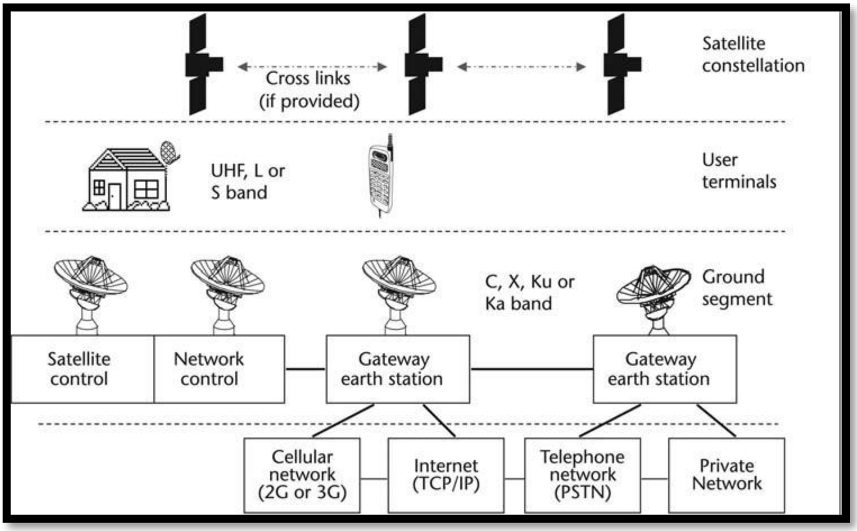

Figure 15.An example of a content distribution network in retail service, using a Ku-band GEO satellite. (*Source:* JSAT International, Inc.)

4.0 SELF ASSESSMENT EXERCISE

Discuss four advantages of Satellite Communication.

5.0 CONCLUSION

You have learnt in this unit the basic concept of satellite communication and its various advantages. You also learnt the use of Microwave Frequencies and the Cable Television.

6.0 SUMMARY

In this unit, you have learnt that:

- Satellites employ microwave radio signals and thereby benefit from the freedom and mobility of wireless connections.
- The phone is oriented so that the back of the modem is pointed toward the satellite position in the equatorial arc.

- Bandwidth is the measure of communication capacity in terms of hertz (Hz), either for the amount of radio spectrum used or for the input information that is delivered to the distant end of the link.
- By providing a repeater station in space, a satellite creates an independent microwave relay for ground-based radio stations.

- The microwave link generally is characterized by the following properties:

  - ✓ Line-of-sight propagation through space and the atmosphere;
  - ✓ Blockage by dense media, like hills, tree trunks, solid buildings, metal walls, and at higher frequencies, heavy rain;
  - ✓ Wide bandwidths, compared to the following lower frequency bands: high frequency (HF) shortwave radio, very high frequency (VHF) TV, frequency modulation (FM) radio, and ultrahigh frequency (UHF) land mobile radio;
  - ✓ Compact antennas typically using metal reflectors, which can focus energy in a desired direction (thus providing gain over an antenna with broad or omni-directional radiation properties);
  - ✓ Transmission through metal waveguide structures as opposed to wire conductors;
  - ✓ Somewhat reduced efficiency of power amplification, which is the ratio of radio frequency (RF) power out divided by the direct current (dc) power in.

7.0 TUTOR MARKED ASSIGNMENT

i. Discuss the fundamentals of satellite systems.
ii. List five basic characteristics of satellites.
iii. Discuss four advantages of satellite communication.
iv. a. What do you understand by Digital transmission?
b. Define the term Transponder.
v. Describe the principles of the Cable Television.

Vi. An earth station is located at 79:34º W longitude and 37:09º N latitude. Calculate its look angle and range to a geosynchronous satellite whose sub-satellite point is located at 102º W longitude.

vii. Briefly describe the usefulness of an antenna in satellite communication.

8.0 REFERENCES/FURTHER READING

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MODULE 2 ATMOSPHERIC SCIENCE & THE SPACE ENVIRONMENT

Unit1 Introduction to Atmospheric science

8.1.1 Scope of Atmospheric Sciences
8.1.2 Meteorology and Forecasting
8.1.3 Weather and Climate

Unit 2 Structure of the Atmosphere

8.1.4 Atmospheric layers and Relation to Temperature
8.1.5 Global Air circulation and Winds
8.1.6 Atmospheric Pressure
8.1.7 Fronts and their Relation to Baroclinic waves

Unit 3 Thermodynamics

8.1.8 Gas Laws, Equations of State (Ideal Gas law), Boyle's and Charles's law
8.1.9 First law of Thermodynamics and Specific Heat
8.1.10 Dry Adiabatic processes and potential temperature

Unit 4 Atmospheric Dynamics

8.1.11 Clouds
8.1.12 Atmospheric kinematics of fluid flow
8.1.13 Atmospheric Dynamics
8.1.14 Weather Prediction

Unit 5 The Space Environment

8.1.15 Where is Space?
8.1.16 The Solar System

UNIT1 INTRODUCTION TO ATMOSPHERIC SCIENCE

CONTENT

1.0 INTRODUCTION

Atmospheric sciences is an umbrella term for the study of the atmosphere, its processes, the effects other systems (such as the oceans) have on the atmosphere, and the effects of the atmosphere on these other systems. It is subdivided into six areas i.e. Meteorology and Forecasting, Atmospheric Physics, Atmospheric Chemistry, Atmospheric Dynamics, Climatology and Extra-terrestrial Planetary Atmospheric Science.

0.0 OBJECTIVES

At the end of this unit, the reader should be able to:

- Define Atmospheric science.
- List the various subdivisions of Atmospheric science.
- Understand the basics of Meteorology and forecasting.
- Draw the weather map observation symbols.
- Differentiate between Weather and Climate.
- Understand the chemical composition of Air.

1.0 MAIN CONTENT

3.1Scope of Atmospheric Sciences

Atmospheric sciences is an umbrella term for the study of the atmosphere, its processes, the effects other systems (such as the oceans) have on the atmosphere, and the effects of the atmosphere on these other systems. *Meteorology* includes atmospheric chemistry and atmospheric physics with a major focus on weather forecasting. *Climatology* is the study of atmospheric changes (both long and short-term) that define average climates and their change over time, due to both natural and anthropogenic climate variability. *Aeronomy* is the study of the upper layers of the atmosphere, where dissociation and ionization are important. Atmospheric science has been extended to the field of planetary science and the study of the atmospheres of the planets of the solar system.... The term *Aerology* is sometimes used as an alternative term (to atmospheric sciences) for the study of Earth's atmosphere.

Major Subdivisions of Atmospheric Sciences

- ✓ Meteorology and Forecasting
- ✓ Atmospheric Physics
- ✓ Atmospheric Chemistry
- ✓ Atmospheric Dynamics
- ✓ Climatology
- ✓ Extraterrestrial Planetary Atmospheric Science

3.2Meteorology and Forecasting

Meteorology focuses on weather and short term forecasting. The name "Meteorology" derives from Aristotle's *Meterologica,* which purported to describe weather and climate. The term *meteor* referred to things that fell from the sky or were found in the sky, and the Greek word meteoros meant "high in the air"or "*raised, lofty, an alteration*".

"Meteorology and climatology are rooted in different parent disciplines, the former in physics and the latter in physical geography. They have, in effect, become interwoven to form a single discipline known as the atmospheric sciences, which is devoted to the understanding and prediction of the evolution of planetary atmospheres and the broad range of phenomena that occur within them." It often combines:

• ***Observation*** (discrete measurements of actual conditions (T, dew point, P, wind, cloud cover, precipitation, etc.) using surface station measurements, radiosonde soundings, radar, satellite data, etc.). These discrete observations are depicted on weather maps using compact weather symbols.

• ***Analysis:*** Accurate long-range weather prediction has proven to be virtually impossible, due to chaotic non-linear phenomena and extreme sensitivity to initial conditions as first discovered by Edward N. Lorenz.

• ***Forecasting*** **(*Predicting Weather*):** Meteorology includes atmospheric chemistry and physics but has a major focus on weather forecasting. Weather-related observations (measurements) are currently made with: Surface stations (including the ASOS systems) Upper-air stations (using radiosondes, rawinsondes, and rocketsondes) Ground-based weather surveillance Radar (WSR). In addition to T °C, Dew Point °C, Wind barb (speed in kts and direction), sky cloud cover, and pressure (SLP mb) or pressure height (dam or m) indicators, weather map observations may include some of the following commonly used symbols (Figure16):

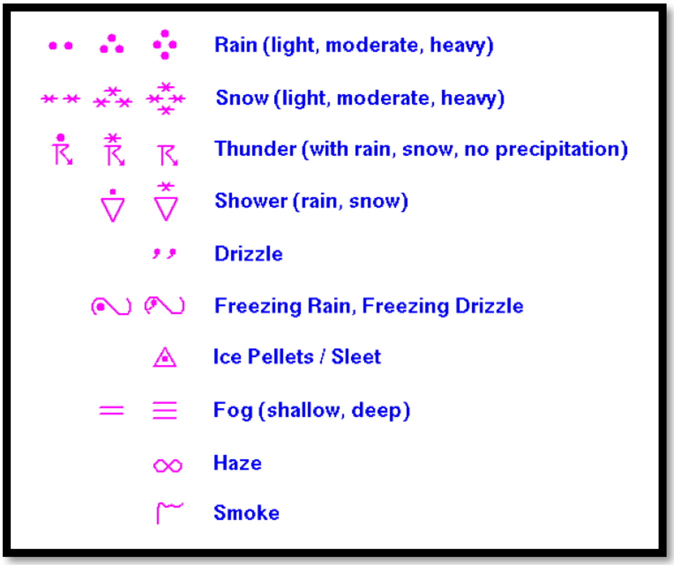

Figure16. Weather map observation symbols.

3.3Weather and Climate

Weather

Weather describes the simultaneous state of certain atmospheric bulk conditions and phenomena in the Earth's troposphere; temperature, humidity or moisture, precipitation, cloud pattern, fog, wind velocity, barometric pressure, etc. at a given place (or over broad areas of the Earth), and at a given time or on a day-to-day basis, or with timescales of at most a few weeks. "When such a collection of weather elements is part of an interrelated physical structure of the atmosphere, it is termed a *weather system*, and includes phenomena at all elevations above the ground."

In contrast, such atmospheric phenomena on much longer timescales are described by *climate*. Neither of these terms includes other atmospheric properties and phenomena such as cosmic rays, other radiations, and chemical constituents.

Climate

Climate refers to the average daily and seasonal weather conditions (such as air temperature, humidity, wind, and precipitation). Seasonal climate prediction is the process of estimating the most probable condition of the average surface temperature and precipitation for the future. Climate prediction is typically expressed as the departure from a long-term average, or so-called normal climate. It is expressed in terms of the probability that subsequent seasonally averaged U.S. temperature and precipitation will be below, above, or near this normal climate state. Climate prediction is different from weather prediction in that it forecasts the most probable averaged state of the environment, rather than the daily sequence of environmental changes.

The IPCC defines climate as follows:

"*Climate* in a narrow sense is usually defined as the 'average weather', or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years. The classical period is 30 years, as defined by the World Meteorological Organization (WMO). These quantities are most often surface variables such as temperature, precipitation, and wind. Climate in a wider sense is the state, including a statistical description, of the climate system."

Climate Variability versus Climate Change

Climate Change and *Variability* describe phenomena affecting the atmosphere (and related effects in the oceans) that are seen over particular time periods lasting months, a few years, or longer.

The phrase *climate change,* a linguistically neutral term though politically somewhat controversial subject appears to be applied to what has been deduced to be human-caused climate changes including *global warming*. It may be termed *anthropogenic climate change* to the extent that this causation has been established; certainly a large fraction of the recent global warming appears anthropogenic.

The Earth's climate is dynamic and naturally varies on seasonal, decadal, centennial, and longer timescales. Each "up and down" fluctuation can lead to conditions which are warmer or colder, wetter or drier, more stormy or quiescent. Analyses of decadal and longer climate records and studies based on climate models suggest that many changes in recent decades can be attributed to human actions; these decadal trends are referred to as *climate change*. The effects of *climate variability* and change ripple throughout the environment and society—indeed touching nearly all aspects of the human endeavour and the environment.

Perhaps the most well understood occurrence of *climate variability* is the naturally occurring phenomenon known as the *El Niño-Southern Oscillation* (*ENSO*), an interaction between the ocean and the atmosphere over the tropical Pacific Ocean that has important consequences for weather around the globe.

The ENSO cycle is characterized by coherent and strong variations in sea-surface temperatures, rainfall, air pressure, and atmospheric circulation across the equatorial Pacific. El Niño refers to the warm phase of the cycle, in which above-average sea-surface temperatures develop across the east-central tropical Pacific. La Niña is the cold phase of the ENSO cycle. The swings of the ENSO cycle typically occur on a time scale of a few years. These changes in tropical rainfall affect weather patterns throughout the world... Climate variability is manifested in other ways as well. Decadal and seasonal shifts in wind patterns and sea surface temperatures in the Atlantic cause changes in hurricane frequency, for example.

Chemical Composition of Air (Fixed and Variable Components):
Tables here are derived from Wikipedia76 and from RAH. See also Standard Atmospheres in Glossary.

Fixed Gases

Gas	**Concentration by Volume**
Nitrogen (N_2)	780,840 ppmv 78.084%)
Oxygen (O_2)	209,460 ppmv 20.946%)
Argon (Ar)	9,340 ppmv 0.9340%)
Carbon dioxide (CO_2)	390 ppmv770.039%)
Neon (Ne)	18.18 ppmv 0.001818%)
Helium (He)	5.24 ppmv 0.000524%)
Methane (CH_4)	1.79 ppmv 0.000179%)
Krypton (Kr)	1.14 ppmv 0.000114%)
Hydrogen (H_2)	0.55 ppmv 0.000055%)
Nitrous oxide (N_2O)	0.3 ppmv 0.00003%)
Carbon monoxide (CO)	0.1 ppmv 0.00001%)
Xenon (Xe)	0.09 ppmv 9×10^{-6}%)
Ozone (O_3)	0.0 to 0.07 ppmv 0 to 7×10^{-6}%)
Nitrogen dioxide (NO_2)	0.02 ppmv 2×10^{-6}%
Iodine (I)	0.01 ppmv 1×10^{-6}%
Ammonia (NH_3)	trace

Variable Components

Gas or Other Component	**Concentration by Volume**
Water vapor (H_2O)	0.40% over full atmosphere, typically 1%–4% at surface
Particulates: dust, pollen and spores, sea spray and salt, volcanic ash	0.01 - 0.15 ppmv
Chlorofluorocarbons (CFCs).	0.0002 ppmv
Misc. industrial and anthropogenic pollutants causing air pollution: Cl_2 and other chlorine compounds, fluorine compounds, Hg, NO (nitric oxide), SO_2 (sulfur dioxide), SO_3 (sulfur trioxide), other sulfur compounds, etc.	variable

4.0 SELF ASSESSMENT EXERCISE

List and explain the Major Subdivisions of Atmospheric Sciences.

5.0 CONCLUSION

In this unit, as a way of introduction, you have learnt the basics of Atmospheric science focusing more on meteorology and forecasting.

6.0 SUMMARY

In this unit you have learnt that:

- *Atmospheric sciences* is an umbrella term for the study of the atmosphere, its processes, the effects other systems (such as the oceans) have on the atmosphere, and the effects of the atmosphere on these other systems.
- *Meteorology* includes atmospheric chemistry and atmospheric physics with a major focus on weather forecasting. *Climatology* is the study of atmospheric changes (both long and short-term) that define average climates and their change over time, due to both natural and anthropogenic climate variability.
- *Aeronomy*is the study of the upper layers of the atmosphere, where dissociation and ionization are important.

- Major Subdivisions of Atmospheric Sciences are: Meteorology and Forecasting, Atmospheric Physics, Atmospheric Chemistry, Atmospheric Dynamics, Climatology and Extra-terrestrial Planetary Atmospheric Science.

7.0 TUTOR MARKED ASSIGNMENT

1. Define Atmospheric Science.
2. List and explain the major subdivisions of Atmospheric science.
3. Differentiate between Weather and climate.
4. Draw the weather map observation symbols.

8.0 REFERENCES/FURTHER READING

Introduction to Atmospheric Science, Summary of notes and materials related to University of Washington introductory course Atm S 301, taught Fall 2010 by Professor Robert A. Houze (RAH), and compiled by Michael C. McGoodwin (MCM).

UNIT 2 STRUCTURE OF THE ATMOSPHERE

CONTENTS

1.0 INTRODUCTION

The Atmosphere is a mixture of gases surrounding any celestial object that has a gravitational field strong enough to prevent the gases from escaping; especially the gaseous envelope of Earth. The principal constituents of the atmosphere of Earth are nitrogen (78 percent) and oxygen (21 percent). The atmospheric gases in the remaining 1 percent are argon (0.9 percent), carbon dioxide (0.03 percent), varying amounts of water vapour, and trace amounts of hydrogen, ozone, methane, carbon monoxide, helium, neon, krypton, and xenon.

4 OBJECTIVES

At the end of this unit the reader should be able to:

- List and explain the atmospheric layers.
- Define Hadley cell, Ferrell cell and polar cell.
- Define Atmospheric pressure.
- Differentiate between Convergence and Divergence inflow of air molecules.
- Explain Fronts and their relation to Baroclinic Waves

5 MAIN CONTENT

3.1Atmospheric Layers and Relation to Temperature

Below is the atmospheric layers listed beginning with the lowest.

Troposphere (0 to 6–20 km)

The troposphere begins at the Earth's surface and extends up to 4-12 miles (6-20 km) high. This is where we live. As the density of the gases in this layer decrease with height, the air becomes thinner. Therefore, the *temperature in the troposphere also decreases with height*. As you climb higher, the temperature drops from about 62°F (17°C) to -60°F (-51°C). Almost all weather occurs in this region... The height of the troposphere varies from the equator to the poles. At the equator it is around 11-12 miles (18-20 km) high, at 50°N and 50°S, 5½ miles and at the poles just under four miles high. The transition boundary between the troposphere and the stratosphere is called the tropopause. Together the tropopause and the troposphere are known as the lower atmosphere.

Stratosphere (6–20 km to ~50–55 km)

The Stratosphere extends from the tropopause up to 31 miles above the Earth's surface. This layer holds 19 percent of the atmosphere's gases but very little water vapour... *Temperature increases with height* as radiation is increasingly absorbed by oxygen molecules leading to the formation of Ozone. The temperature rises from an average -76°F (-60°C) at tropopause to a maximum of about 5°F (-15°C) at the stratopause due to this absorption of ultraviolet radiation. This increase is temperature with height means no "convection" occurs since there is no vertical movement of the gases... The transition boundary which separates the stratosphere from the mesosphere is called the stratopause. The regions of the stratosphere and the mesosphere, along with the stratopause and mesopause, are called the middle atmosphere by scientists.

Mesosphere (~50–55 km to 80–85 km)

The mesosphere extends from the stratopause to about 53 miles (85 km) above the earth. The gases, including the oxygen molecules, continue to become thinner and thinner with height. As such, the effect of the warming by ultraviolet radiation also becomes less and less leading to *a decrease in temperature with height*. On average, temperature decreases from about 5°F (-15°C) to as low as -184°F (-120°C) at the mesopause. However, the gases in the mesosphere are still thick enough to slow down meteorites hurtling into the atmosphere, where they burn up, leaving fiery trails in the night sky.

Thermosphere (80–85 km to 690 km)

The Thermosphere extends from the mesopause to 430 miles (690 km) above the earth. This layer is known as the upper atmosphere... The gases of the thermosphere are increasingly thinner than in the mesosphere. As such, incoming high energy ultraviolet and x-ray radiation from the sun, absorbed by the molecules in this layer, causes a large temperature increase. Because of this absorption, the *temperature increases with height* and can reach as high as 3,600°F (2,000°C) near the top of this layer; however, despite the high temperature, this layer of the atmosphere would still feel very cold to our skin because of the extremely thin air. The total amount of energy from the very few molecules in this layer is not enough to heat our skin.

Exosphere (690 km to 10,000 km)

The Exosphere is the outermost layer of the atmosphere. It extends from the thermopause—the transition boundary which separates the exosphere from the thermosphere below—to 6,200 miles (10,000 km) above the earth. In this layer, atoms and molecules escape into space and satellites orbit the earth.

3.2Global Air Circulation and Winds

Although many regions have special winds of their own (partially discussed below), there are certain generalizations that can be made about global wind patterns. Such discussion invariably starts with an idealized model of an ocean planet (Figure17) having no land surfaces and with rotation in the same direction of the Earth but with no rotational axis tilt with respect to the sun. Computations using this model predict the following patterns:

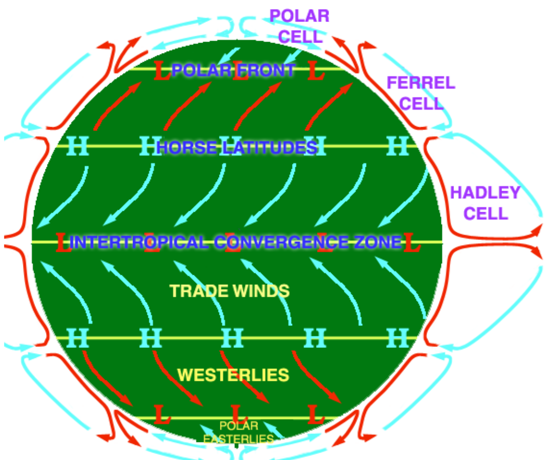

Figure17. Idealized ocean planet model surface winds and vertical circulations from http://en.wikipedia.org/wiki/Global_winds

With the addition of the Earth's major land masses, which are much more extensive in the NH than the SH, plus the planetary tilt of 24.4º (varying from 22.1° to 24.5º), we get a more typical model of Earth pattern of winds (still ignoring in this diagram any seasonal or local wind variations) Figure18:

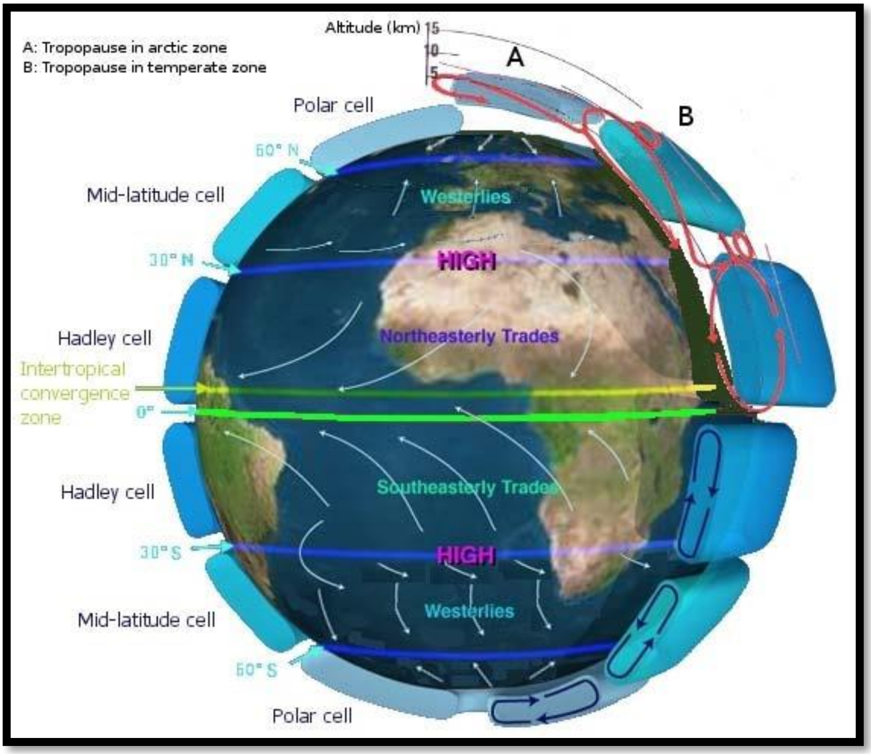

Figure18. Realistic averaged global air circulations from Wikipedia http://en.wikipedia.org/wiki/Global_winds

These diagrams show the directions prevailing for surface winds, including the trades and the mid-latitude westerlies (in both hemispheres). The Intertropical Convergence Zone is discussed below. The Hadley cell (named after George Hadley) and the Mid-latitude cell depict major vertical and upper level components of normal global atmosphere circulation. The Polar cell is indicated but not discussed in detail. The Mid-latitude cell here is also called a *Ferrel cell* (named after William Ferrel). The decrease in height of the tropopause going from Equator to Pole is depicted in exaggerated scale. Various aspects of this global circulation are mentioned throughout this summary. Of course this wind pattern also affects precipitation.

These features can be summarize as follows:
"Instead of one large circulation between the poles and the equator, there are three circulations...

1. **Hadley cell**: Low latitude air movement toward the equator that with heating, rises vertically, with poleward movement in the upper atmosphere. This forms a convection cell that dominates tropical and sub-tropical climates.
2. **Ferrel cell**: A mid-latitude mean atmospheric circulation cell for weather named by [William] Ferrel in the 19th century. In this cell the air flows poleward and eastward near the surface and equatorward and westward at higher levels.
3. **Polar cell**: Air rises, diverges, and travels toward the poles [at about 60º]. Once over the poles, the air [converges aloft and] sinks, forming the polar [surface] highs. At the surface, air diverges outward from the polar highs. Surface winds in the polar cell are easterly (polar easterlies). Between each of these circulation cells are bands of high and low pressure at the surface.

3.3 Atmospheric Pressure

Air is held to the earth by gravity. This strong invisible force pulls the air downward, giving air molecules weight. The weight of the air molecules exerts a force upon the earth and everything on it. The amount of force exerted on a unit surface area (a surface that is one unit in length and one unit in width) is called atmospheric pressure or air pressure. The air pressure at any level in the atmosphere can be expressed as the total weight of air above a unit surface area at that level in the atmosphere. Higher in the atmosphere, there are fewer air molecules pressing down from above. Consequently, air pressure always decreases with increasing height above the ground. Because air can be compressed, the density of the air (the mass of the air molecules in a given volume) normally is greatest at the ground and decreases at higher altitudes.

Convergence and Divergence: *Convergence* aloft (a net inflow of air molecules into a region of the atmosphere) is associated with increasing surface pressure, since the mass overhead per unit surface area, or weight of the column, will increase with time. In contrast, *divergence* aloft (a net outflow of air molecules from a region of the atmosphere) is always associated with decreasing surface pressure, since the mass per unit surface area, or weight of the column, will decrease with time. A high surface pressure develops under a region of maximum convergence aloft. A low surface pressure develops under a region of maximum divergence aloft. In general, rising air motion is associated with decreasing (*Low*) pressure (at least at the surface), adiabatic cooling, increasing relative humidity, condensation, clouds and precipitation. In contrast, sinking air motion is associated with increasing (*High*) pressure (at the surface), adiabatic warming, decreasing relative humidity, and relatively clear skies.

Troughs and Ridges, Normal and Cut-off Lows and Highs, Blocking Highs: These are most easily understood as phenomena defined on constant pressure surfaces. The large-scale (synoptic) pattern of the 500 mb surface apparent in views centered on the N Pole shows concentric pressure height contours corresponding with westerlies which encircle the pole (geostrophic wind flow direction is along the pressure height contours). Typically the pressure height isohypse contours are circumpolar contours which decrease in height value with increased latitude.

There are large wave-like perturbations in the circularity of these pressure height contours. These waves, called *baroclinic or Rossby waves*, are associated with *troughs* (which are elongated regions of relatively low or depressed pressure height surfaces, often associated with weather fronts) and *ridges* (which are elongated regions of relatively high or elevated pressure height surfaces).

Wind Response to Pressure Gradients: Wind direction is not usually perpendicular to the isohypse (pressure height) contours (as one might naively expect, assuming air flow were simply directed along the pressure gradient, but this is true only at the Equator where Coriolis effect is absent, or would also be true for a non-rotating Earth). Rather, under the influence of the Coriolis Effect and a low Rossby number for large-scale flows, it is everywhere nearly parallel to isohypse contours. For example, the polar jet streams, which flow nearly parallel to pressure height contours for which pressure height and temp is decreasing toward the poles, are westerly winds in both hemispheres.

3.4Fronts and Their Relation to Baroclinic Waves

A **Front**is the warm edge of a zone of strong temperature contrast." (Other sources define a front as the transition zone between [or boundary separating] two air masses of different densities.)116 Cold air always underlies warmer air, due to its greater density. Apparently, fronts are weather phenomena at and near the surface.

Cold Front: A *cold front*, symbolized by  is a front in which cold air behind the front is advancing toward receding warm air.117Cold fronts have a steeply sloping interface with the less dense warm air. They lift the warm air below which they advance abruptly, and cause a more concentrated formation of clouds and precipitation above the advancing front.

Warm Front: A *warm front*, symbolized by  moves toward and over colder air, retreating from warm air behind it. The interface between a warm front and the cold air it is overriding has a more gradual slope along which the warm air gradually rises, causing more horizontally widespread cloud formation and precipitation.

Occluded Front: An *occluded front*, symbolized byby  is one in which the cold air front has caught up with (overtaken) and partly overridden a warm front, forcing warm air aloft. It exhibits a gradually lowering cloud base, followed by precipitation and then a rapidly rising cloud base. "An occluded front is formed during the process of *cyclogenesis* [the development or strengthening of cyclonic circulation in the atmosphere about a low pressure area] when a cold front overtakes a warm front. When this occurs, the warm air is separated (occluded) from the cyclone centreat the Earth's surface. The point where the front and the occluded front meet (and consequently the nearest location of warm air to the centre of the cyclone) is called the triple point... There are two types of occlusion, warm and cold. In a cold occlusion, the air mass overtaking the warm front is cooler than the cool air ahead of the warm front, and prows under both air masses.

In a warm occlusion, the air mass overtaking the warm front is not as cool as the cold air ahead of the warm front, and rides over the colder air mass while lifting the warm air... A wide variety of weather can be found along an occluded front, with thunderstorms possible, but usually their passage is associated with a drying of the air mass. Additionally, cold core funnel clouds are possible if shear is significant enough along the cold front. Occluded fronts are indicated on a weather map by a purple line with alternating semicircles and triangles pointing in direction of travel. Occluded fronts usually form around mature low pressure areas.

4.0 SELF ASSESSMENT EXERCISE

Briefly explain the different atmospheric layers and their relations to temperatures.

5.0 CONCLUSION

We learnt in Unit 2 that the earth's atmospheric layer is divided into 5 layers, namely: troposphere, stratosphere, mesosphere, thermosphere and exosphere.

6.0 SUMMARY

In this unit, we learnt that:

- The troposphere begins at the Earth's surface and extends up to 4-12 miles (6-20 km) high.
- The Stratosphere extends from the tropopause up to 31 miles above the Earth's surface.

- The mesosphere extends from the stratopause to about 53 miles (85 km) above the earth. The gases, including the oxygen molecules, continue to become thinner and thinner with height.
- The Thermosphere extends from the mesopause to 430 miles (690 km) above the earth. This layer is known as the upper atmosphere. The gases of the thermosphere are increasingly thinner than in the mesosphere.
- The Exosphere is the outermost layer of the atmosphere. It extends from the thermopause—the transition boundary which separates the exosphere from the thermosphere below—to 6,200 miles (10,000 km) above the earth.
- **Hadley cell**: Low latitude air movement toward the equator that with heating, rises vertically, with poleward movement in the upper atmosphere.
- **Ferrel cell**: A mid-latitude mean atmospheric circulation cell for weather named by [William] Ferrel in the 19th century.
- **Polar cell**: Air rises, diverges, and travels toward the poles [at about 60º].
- *Convergence* (a net inflow of air molecules into a region of the atmosphere) is associated with increasing surface pressure, since the mass overhead per unit surface area, or weight of the column, will increase with time.
- *Divergence* (a net outflow of air molecules from a region of the atmosphere) is always associated with decreasing surface pressure, since the mass per unit surface area, or weight of the column, will decrease with time.

7.0 TUTOR MARKED ASSIGNMENT

1. Differentiate between Convergence and Divergence of net inflow of air molecules.
2. List and briefly explain the 5 atmospheric layers.
3. Define Atmospheric pressure.

8.0 REFERENCES/FURTHER READING

Introduction to Atmospheric Science, Summary of notes and materials related to University of Washington introductory course Atm S 301, taught Fall 2010 by Professor Robert A. Houze (RAH), and compiled by Michael C. McGoodwin (MCM).

Introductory Astronomy & Astrophysics 4th edition, M. Zeilik& S. A. Gregory, Saunders College Publishing.

The Stars: their structure and evolution, R. J. Tayler, CUP, 2nd edition Basic text of stellar structure.

UNIT 3 THERMODYNAMICS

CONTENTS

1.0 INTRODUCTION

Thermodynamics is a field of physics that describes and correlates the physical properties of macroscopic systems of matter and energy. The principles of thermodynamics are of fundamental importance to all branches of science and engineering. A central concept of thermodynamics is that of the macroscopic system, defined as a geometrically isolable piece of matter in coexistence with an infinite, unperturbable environment.

2.0 OBJECTIVES

At the end of this unit the reader should be able to:

- Define Thermodynamics.
- State the Gas laws.
- Derive the ideal gas equation.
- Differentiate between the Ideal gas equation of State for a specific gas using mass (m) & Specific Gas Constant R from the Ideal gas equation (Equation of State) for any ideal gas using moles & the Universal Gas Constant R*
- Show that The virtual temperature ***Tv is given by***

$$T_v \equiv \frac{T}{[1-\frac{e}{p}(1-\varepsilon)]}$$

- Define Geopotential.
- State the laws of thermodynamics.
- Explain Adiabatic processes.

3.0 MAIN CONTENT

3.1 Gas Laws, Equation of State (Ideal Gas Law), Boyle's and Charles's Laws

PV = mRT is the Ideal gas equation (Equation of State) for a specific gas using mass (m) & Specific Gas Constant R.

PV = nR*T is the Ideal gas equation (Equation of State) for any ideal gas using moles & the Universal Gas Constant R*

Boyle's Law: states that if only Temperature (T) and mass (m) are held constant, Volume is inversely proportional to Pressure.

Charles's Law I: states that If only Pressure (P) and mass (m) are held constant, the Volume is proportional to Temperature.

Charles's Law II: states that If only Volume (V) and mass (m) are held constant, the Pressure is proportional to the Temperature (T).

Virtual Temperature and Equations of State for Dry and Moist Air

$P_d = \rho R_d T$ is the Equation of State for dry air

The *virtual temperature* T_v is a fictitious temperature allowing expression of the Equation of State with moisture present using overall density ρ, R_d, and T_v:

Given $\rho = \frac{(md + mv)}{V}$

Overall density is sum of dry air density component + water vapor component) and T_v (Virtual Temperature), defined as

$$T_v \equiv \frac{T}{[1-\frac{e}{p}(1-\varepsilon)]} = \frac{T}{(1-0.378\frac{e}{p})}$$

Then

$$p = \rho R_d T_v$$

Thus the total pressure is given by gas law for dry air using the virtual temperature.

Note that since **$e/p < 1$, $T_v \geq T$, and $\rho = p/R_dT_v$,** then *moist air has lower density and is therefore lighter than dry air*.

Hydrostatic Equation, Geopotential Φ (z) and Height Z, Hypsometric Equation

For equilibrium (static, non- convecting) conditions in which downward gravitational force is nearly balanced by pressure, **The Hydrostatic Equation**, giving rate of change of pressure with density and local gravity g, is:

$$\frac{\partial p}{\partial z} = -\rho g(\Phi, Z)$$

Geopotential, defined as work required to raise 1 kg to geometric height z (units in J kg^{-1}):

$$\Phi(Z) = \int_0^Z g(\Phi, z)dz$$

thus, it is a function of height and the non-constant local g.

Geopotential Height, using globally averaged standard acceleration g0 and geopotential is defined as:

$$\mathbf{Z} = (z)/\mathbf{g_0}$$

Note that the definition uses constant $g_0 \equiv 9.80665\ ms^{-2}$ (defined exactly) rather than varying g.

Because g decreases with height (i.e., for elevations above mean sea level, g is < $g_0 \equiv 9.80665\ ms^{-2}$), the geopotential height Z at higher elevations is lower than (or underestimates) the actual geometric height z, a discrepancy that becomes more pronounced at much greater distances from the Earth than found in the troposphere.

Geopotential thickness of a layer between pressure levels

$$\mathbf{Z_2\text{-}Z_1=\frac{R_d}{g_0}\int_{p_2}^{p_1} T_v \frac{d_p}{p}}$$

Hydrostatic Equation using geopotential height Z and g_o:

$$\frac{\partial p}{\partial z} = -\rho g_o$$

Or

$$\frac{\partial z}{\partial p} = \frac{1}{-\rho g_o}$$

Hypsometric Equation (HE): The Geopotential thickness of a layer between 2 pressures using mean virtual temperature Tv is given by:

$$Z_2 - Z_1 = \frac{R_d}{g_o}\overline{T}_V \ln\frac{P_1}{P_2}$$

The hypsometric equation is used for mapping pressure surfaces and/or layer thicknesses, which serve as a forecasting tool. Note that as $\overline{T}_V$ increases, the layer becomes thicker—thickness of a layer is greater where air is warmer.

Warm cores lows (lows with warmer center than periphery, as seen in hurricanes) exhibit near the ground depression of isohypse pressure height surfaces and greater thickness of layers (wider spacing of isohypse contours), corresponding to greatest intensity winds near the ground. These may underlie a high aloft.

“Upper level lows, as seen with occlusions, may be cold core lows that do not always extend downward to the ground. In these cases, “It follows from the HE that these lows must be cold core below the level at which they achieve their greatest intensity and warm core above that level...”

Reduction of Pressure to Sea Level

This adjustment of pressure to a common reference elevation at sea level is done to make reporting of pressure meaningful with respect to weather effects over terrain that varies in surface elevation. Note that despite the name, “reduction” of a higher station pressure to sea level involves increasing the computed pressure value. Comparing computed sea level pressure p0 and the actual surface ground level pressure pg of the non-sea level station at Geopotential height Zg.

$$p_O = p_g \exp(\frac{g_o Z_g}{R_d \overline{T}_v})$$

or, for small Zg and Zg/H ≪ 1:

$$p_O - p_g \cong p_g \exp(\frac{g_o Z_g}{R_d \overline{T}_v})$$

Where and Rd = 287.0 J K^{-1} kg^{-1}

For surface locations that are at substantially high elevation (such as Leadville, CO, at 3096 m or about 700 mb), a small error in actual surface pressure determination leads to a large discrepancy in pressure reduced to sea level. Therefore, it is common to smooth the surface isobars in drawing surface maps, particularly for such high-altitude stations and other stations that might have pressure reporting errors.

3.2 First Law of Thermodynamics and Specific Heat

This expresses the conservation of energy. For an ideal gas (working substance) of mass m, fully enclosed in an insulated cylindrical container bounded at one end by a moveable piston and at the other with a fixed wall, when heat dQ (in J) is added to the gas, the heat may increase the internal energy of the gas dU (in J) and/or do work dW on or by the environment (in J, in this case interacting with the piston).

First Law of Thermodynamics (1) states:

$$\boldsymbol{dQ - dW = dU}$$

These variables change independent of the manner in which the system moves between the two states. The work performed may be visualized on a p-V thermodynamic diagram.

Specific heat (mass-specific heat capacity) of a gas at constant volume is defined as:

$$\boldsymbol{C_v = \left(\frac{dQ}{dT}\right)_{vConstant}}$$

per unit mass (units are therefore J K^{-1} kg^{-1})

Specific heat (mass-specific heat capacity) of a gas at constant pressure is defined as:

$$\boldsymbol{C_p = \left(\frac{dQ}{dT}\right)_{pConstant}}$$

per unit mass (J K^{-1} kg^{-1})

Then **the First Law (2)** is alternatively, for α = specific volume, given by

$$dQ = dU + pda$$

First Law (3) for ideal gas, expressed per unit mass:

$$dQ = C_v d_T + pda$$

FLT (4) for ideal gas, expressed per unit mass, useful as it uses P and T:

$$dQ = C_P d_T - adp$$

3.3 Dry Adiabatic Processes and Potential Temperature

Adiabatic processes are processes for which dQ = 0, no heat is added or removed. When dry parcels of air are "lifted" rapidly so that there is no condensation or evaporation and no radiation, then the process is "dry–adiabatic". Note: Until condensation forms at the LCL moist unsaturated parcels that are lifted also follow a dry adiabat and for them the process is also "dry-adiabatic".

For dry adiabatic conditions:

$$\mathbf{p\alpha = R_dT}$$

the *Dry adiabatic lapse rate in p-coordinates* is:

$$\frac{dT}{dp} = \frac{\alpha}{C_p} > 0$$

Presumably it is this definition of lapse rate which justifies the labeling by some of the dry adiabats on the STLPD as Γ_d, although in other contexts Γ_d seems to pertain to height.

The dry adiabatic lapse rate Γ_d is given by

$$\Gamma_d \equiv -\left(\frac{\partial T}{\partial Z}\right)_{dryparcel} = -\rho g_o$$

Note that the differential ∂z is replaced by ∂Z, quantities that are apparently nearly interchangeable for troposphere heights.

Also, for adiabatic process,

$$CpdT - \alpha\, dp = 0$$

Therefore, T as a function of Z is:

$$T_2 = T_1 - \frac{g_o}{C_p}(Z_2 - Z_1)$$

This makes the assumption of hydrostatic balance.

A more exact alternative form expressing T as a function of P:

$$\boldsymbol{T_2 = T_1 (\frac{p_2}{p_1})^{\frac{R_d}{C_p}}}$$

Which is exact, as does not assume hydrostatic balance. Note that the exponent is ≈ 0.286.

4.0 SELF ASSESSMENT EXERCISE

Define Geopotential and write the mathematical expression defining all terms.

5.0 CONCLUSION

In this unit, we learnt that **PV = mRT** is the Ideal gas equation (Equation of State) for a specific gas using mass (m) & Specific Gas Constant R while **PV = nR*T** is the Ideal gas equation (Equation of State) for any ideal gas using moles & the Universal Gas Constant R*. Also, that the Adiabatic processes are processes for which dQ=0, no heat is added or removed.

6.0 SUMMARY

In this unit, we learnt that:

- **Boyle's Law**: states that if only Temperature (T) and mass (m) are held constant, Volume is inversely proportional to Pressure.
- **Charles's Law I**: states that If only Pressure (P) and mass (m) are held constant, the Volume is proportional to Temperature.
- **Charles's Law II**: states that If only Volume (V) and mass (m) are held constant, the Pressure is proportional to the Temperature (T).

- **Geopotential**, defined as work required to raise 1 kg to geometric height z (units in J kg^{-1}).
- **First Law of Thermodynamics (1) states**:

$$dQ - dW = dU$$

- **The First Law (2)** is alternatively, for α = specific volume, given by

$$dQ = dU + pda$$

- **First Law (3) for ideal gas**, expressed per unit mass:

$$dQ = C_v d_T + pda$$

- **First law of thermodynamics (4) for ideal gas**, expressed per unit mass, useful as it uses P and T:

$$dQ = C_P d_T - adp$$

7.0 TUTOR MARKED ASSIGNMENT

1. State the First law of Thermodynamics for 4 different states.

2. What do you understand by Adiabatic process.
3.Define Specific heat capacity.
4. Write down the expression for Dry adiabatic lapse rate in p-coordinates.

8.0 REFERENCES/FURTHER READING

Introduction to Atmospheric Science, Summary of notes and materials related to University of Washington introductory course Atm S 301, taught Fall 2010 by Professor Robert A. Houze (RAH), and compiled by Michael C. McGoodwin (MCM).

Introductory Astronomy & Astrophysics 4th edition, M. Zeilik& S. A. Gregory, Saunders College Publishing.

The Stars: their structure and evolution, R. J. Tayler, CUP, 2nd edition
Basic text of stellar structure.

UNIT 4 ATMOSPHERIC DYNAMICS
CONTENTS

1.0 INTRODUCTION

Atmospheric Dynamics deals in part with the flow of fluids and gases in the atmosphere, as derived from the laws of motion such as F = ma, etc. Wikipedia states, "Atmospheric dynamics involves the study of observations and theory dealing with all motion systems of meteorological importance. The list includes diverse phenomena as thunderstorms, tornadoes, gravity waves, tropical cyclones, extra-tropical cyclones, jet streams, and global-scale circulations. The goal of dynamical studies is to explain the observed circulations on the basis of fundamental principles from physics.

2.0 OBJECTIVES

At the end of this unit the reader should be able to:

- Know how Clouds are formed.
- Classify clouds based on atmospheric layers.
- Differentiate between Thunderstorms and Clouds.
- Explain the formation of Thunderstorm.
- Explain Atmospheric Kinematics of Fluid Flow.

- List and explain the various types of cloud predictions.

3.0 MAIN CONTENT

3.1 Clouds

This is a large subject and I only touch on selected topics. Clouds tend to form by air rising, expanding, and cooling. They occur due to

- Surface heating and free convection
- Uplift along topography including mountains
- Widespread ascent due to convergence of surface air
- Uplift along weather fronts.

Cloud Classification by Atmosphere layers

The layers of the various types of clouds are:

S/N	Cloud Name	Polar	Mid-Latitude	Tropics
1	**Cumulus (Cu) Cumulonimbus (Cb) Stratus (St) Stratocumulus (Sc) Nimbostratus (Ns)** [**Fog**—at ground level]	< 2 km	< 2km	< 2 km
2	**Altostratus (As) Altocumulus (Ac)**	2 – 4 km	2 – 7 km	2 – 8 km
3	**Cirrus (Ci) Cirrostratus (Cs)**	3 – 8 km	5 – 13 km	6 – 18 km

	Cirrocumulus (Cc)			

3.2 Thunderstorms

Thunderstorms are very tall clouds that extend from near the ground up to, and often slightly above, the top of the troposphere, the bottom layer of the atmosphere. A thunderstorm has a characteristic cylindrical or slight hour-glass shape with a puffy, cauliflower texture. Clouds with this texture are called cumulus, and clouds that produce rain are called nimbus. Because thunderstorms are a combination of these two, they are called cumulonimbus clouds. Many thunderstorms develop an anvil-shaped top as the top is cut-off by high-altitude wind. Severe thunderstorms can produce hail, strong winds, and tornadoes. Weak thunderstorms are called thundershowers. Some thundershowers are so weak that they produce *virga*, which is rain falling from the cloud that evaporates before reaching the ground.

Formation of thunderstorm

Thunderstorms form when the air close to the ground is warm and humid. When this warm air lifts, it becomes cooler, and the water vapor in the air condenses, forming a cloud. If the cloud is warmer than the surrounding unsaturated (cloudless) air, then the cloud will continue to rise. This causes the cloud to accelerate upward in the form of turbulent bubbles, giving the cloud its characteristic cumulus shape. A variety of conditions can cause the lifting needed to initiate these clouds, including the heating of the ground, wind blowing up and over a mountain, sea breezes, cold fronts, and tropical low-pressure systems. The greater the temperature difference between the relatively warm cloud and its surrounding air, the more vigorous the thunderstorm will be. If the wind speed and wind direction change significantly with height, the thunderstorm can rotate. These rotating thunderstorms provide the circulation that, when concentrated in a small area, result in a tornado.

Because thunderstorms require warm, moist air, they occur most frequently in the tropics. In temperate latitudes, they are more likely to occur during the hot summer than during the cooler seasons. Over land, thunderstorms occur most frequently in the afternoon and early evening because land surfaces heat up dramatically during the day and cool down at night. In contrast, thunderstorms at sea are equally likely to occur at all hours because large water surfaces maintain an even temperature throughout the day.

3.3 Atmospheric Kinematics of Fluid Flow

Kinematics (from Greek 'to move') is the branch of classical mechanics that describes the motion of bodies (objects) and systems (groups of objects) without consideration of the forces that cause the motion.20
In describing moving fluids, the following definitions apply to lines of flow:

- *Streamlines* "are a family of curves that are instantaneously tangent to the velocity vector of the flow.
- *Streaklines*"are the locus of points of all the fluid particles that have passed continuously through a particular spatial point in the past. Dye steadily injected into the fluid at a fixed point extends along a streakline."
- *Pathlines*"are the trajectories that individual fluid particles follow. These can be thought of as a 'recording' of the path a fluid element in the flow takes over a certain period. The direction the path takes will be determined by the streamlines of the fluid at each moment in time."

For a locally defined wind blowing along or parallel to wind contours (*streamlines*) that indicate wind direction:
V = instantaneous horizontal wind velocity magnitude,
s = natural coordinate expressing incremental displacement component along and parallel to the streamline
n = natural coordinate expressing displacement component perpendicular to s and the streamline
ψ = angle between the streamline or displacement s and an arbitrary fixed coordinate system such as x-y.

Note that the instantaneous directions of the streamlines evolve and do not correspond exactly with the actual horizontal trajectories (path lines) taken.

3.4 Atmospheric Dynamics

Dynamics involves the study of the time evolution of physical processes under the influence of the laws affecting motion including **F =ma (where F is force in newtons, m is mass in kilograms and "a" is acceleration due to gravity in ms**$^{-2}$).

Atmospheric Dynamics deals in part with the flow of fluids and gases in the atmosphere, as derived from the laws of motion. Atmospheric dynamics involves the study of observations and theory dealing with all motion systems of meteorological importance.

The list includes diverse phenomena as thunderstorms, tornadoes, gravity waves, tropical cyclones, extratropical cyclones, jet streams, and global-scale circulations. The goal of dynamical studies is to explain the observed circulations on the basis of fundamental principles from physics. The objectives of such studies include improving weather forecasting, developing methods for predicting seasonal and interannual climate fluctuations, and understanding the implications of human-induced perturbations (e.g., increased carbon dioxide concentrations or depletion of the ozone layer) on the global climate.

3.5 Weather Prediction

Weather Prediction from Local Signs: This has been the subject of human experience and popular wisdom for millennia, at least back to Theophrastus. A valid example is: A halo around the sun or moon means that rain is on the way. Another familiar example: "Red Sky in the Morning, Sailors Warning; Red Sky at Night, Sailors Delight". "This saying only applies to mid-latitude locations (winds are easterly in the tropics and in the high latitudes the sun rises and sets at a large deviation from the east-west trajectory). Storm systems in the middle latitudes generally move west to east. A red sky in the morning implies the rising sun in the east is shining on clouds to the west and conditions are clear to the east. Clouds moving from the west indicate an approaching storm system. A red sky at night implies the sun (setting in the west) is shining on clouds to the east and conditions are clear to the west (because the sun can be seen setting). If you can see the sunset, the sky will be redder. Clouds to the east indicate an exciting storm system in the middle latitudes. Upper level clouds are noted for giving the sky a reddish hue during dawn or dusk.

Note:

If you can see the sunrise but the west part of the sky is dark: look out for approaching bad weather.

If you can see the sunset: the weather conditions will be nice.

Types of Weather Prediction

- ✓ **Cloud Watching**: One can infer warm advection aloft (increasing air stability) and cold advection aloft (increasing air instability, towering cumulus, and showers) by watching the clouds. Winds that *veer* (change direction clockwise) with height indicate warm advection, whereas winds that *back* (change direction counter clockwise) with height indicate cold advection (Horizontal transfer of heat by air).
- ✓ **Surface Charts**: These are useful for short-range weather prediction, especially if we have maps from several days previously as well. The following rules of thumb are used:

(1) Mid-latitude cyclonic storms and fronts tend to move in the same direction and at approximately the same speed as they did during the previous 6 hours.

(2) Low pressure areas tend to move in a direction that parallels the isobars in the warm air ahead of the cold front.

(3) Lows tend to move toward the region of greatest pressure drop, while highs tend to move toward the region of greatest rise.

- ✓ **Numerical Prediction**: Modern weather prediction begins with *Numerical Weather prediction*. "Numerical weather prediction uses current weather conditions as input into mathematical models of the atmosphere to predict the weather. Numerical Weather prediction typically assumes independent variables or coordinates (x,y.p,t), where t is time. Note that pressure here is used as the vertical coordinate, one of the 4 independent variables (whereas geopotential height Z is considered a dependent variable). Within this coordinate system, the goal of weather prediction is to predict the course of 6 dependent variables (T, ρ, Z, u, v, ω), starting with an initial state of these dependent variables and determining how they evolve.

4.0 SELF ASSESSMENT EXERCISE

Extensively discuss the classification of clouds based on atmospheric layers.

5.0 CONCLUSION

In this unit we learnt that clouds occur due to; Surface heating and free convection, Uplift along topography including mountains, Widespread ascent due to convergence of surface air and Uplift along weather fronts.

6.0 SUMMARY

In this unit we learnt that:

- Clouds are form by air rising, expanding, and cooling.
- Clouds occur due to:
  - ✓ Surface heating and free convection
  - ✓ Uplift along topography including mountains
  - ✓ Widespread ascent due to convergence of surface air
  - ✓ Uplift along weather fronts.
- Thunderstorms are very tall clouds that extend from near the ground up to and often slightly above, the top of the troposphere, the bottom layer of the atmosphere.

- A thunderstorm has a characteristic cylindrical or slight hour-glass shape with a puffy, cauliflower texture.
- Clouds with this texture are called cumulus, and clouds that produce rain are called nimbus.
- Weak thunderstorms are called thundershowers.
- Thunderstorms form when the air close to the ground is warm and humid. When this warm air lifts, it becomes cooler, and the water vapour in the air condenses, forming a cloud.
- *Streamlines* "are a family of curves that are instantaneously tangent to the velocity vector of the flow.
- *Streaklines*"are the locus of points of all the fluid particles that have passed continuously through a particular spatial point in the past. Dye steadily injected into the fluid at a fixed point extends along a streakline."
- *Pathlines*"are the trajectories that individual fluid particles follow.
- Atmospheric dynamics involves the study of observations and theory dealing with all motion systems of meteorological importance.

7.0 TUTOR MARKED ASSIGNMENT

1. Briefly explain the formation of Clouds.

2. What are the causes of the occurrences of clouds?

3. Using a table, show the classifications of cloud based on atmospheric layers.

4. Briefly discuss the formation of Thunderstorm.

5. Define the following in application to lines of flow:
a. Streamline
b. Streaklines
c. Pathlines

8.0 REFERENCES/FURTHER READING

Introduction to Atmospheric Science, Summary of notes and materials related to University of Washington introductory course Atm S 301, taught Fall 2010 by Professor Robert A. Houze (RAH), and compiled by Michael C. McGoodwin (MCM).

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The Stars: their structure and evolution, R. J. Tayler, CUP, 2nd edition Basic text of stellar structure.

UNIT 5 THE SPACE ENVIRONMENT

CONTENTS

0.0 INTRODUCTION

Space is a place. Some people think of space as a nebulous region far above their heads extending out to infinity. But for us, space is a place where things happen: spacecraft orbit Earth, planets orbit the Sun, and the Sun revolves around the centre of our galaxy. In this module we'll look at this place we call space, exploring where it begins and how far it extends. We'll see that space is actually very close. Then, starting with our "local neighbourhood," we'll take a mind-expanding tour beyond the galaxy to see what's in space. Next we'll see what space is like. Before Astronauts takes any trip, they usually check the weather to see how they must prepare themselves and their machines to handle this hostile environment. Although in the night sky the Moon looks really far away, Earth's atmosphere is relatively shallow, so space is close.

2.0 OBJECTIVES

To be able to:

• Explain where space begins and describe our place in the universe.

• List the major hazards of the space environment and describe theireffects on spacecraft.

• List and describe the major hazards of the space environment that pose a problem for humans living and working in space.

3.0MAIN CONTENT

3.1Key Concepts of this Unit

• For our purposes, space begins at an altitude where a satellite can briefly maintain an orbit. Thus, space isclose. It's only about 130 km (81 mi.) straight up.

• The Sun is a fairly average yellow star which burns by the heat of nuclear fusion. Its surface temperature is more than 6000K and its output includes; Electromagnetic radiation that we see and feel here on Earth as light and heat, Streams of charged particles that sweep out from the Sun as part of the solar wind, and Solar particle events or solar flares, which are brief but intense periods of charged-particle emissions.

• Our galaxy is just one of billions and billions of galaxies in the universe.

3.2 Where is Space?

If space is a place, where is it? Safe within the cocoon of Earth's atmosphere, we can stare into the night sky at thousands of stars spanning millions of light years. We know space begins somewhere above our heads, but how far? If we "push the envelope" of a powerful jet fighter plane, we can barely make it to a height where the sky takes on a purplish colour and stars become visible in daylight. But even then, we're not quite in space. Only by climbing aboard a rocket can we escape Earth's atmosphere into the realm we normally think of as space. But the line between where the atmosphere ends and space begins is, by no means, clear (see: ***https://www.faa.gov/about/office_org/headquarters_offices/avs/offices/aam/cami/library/online_libraries/aerospace_medicine***).

In fact, there is no universally accepted definition of precisely where space begins. To earn astronaut wings, for example, you must reach an altitude of more than 92.6 km (57.5 mi.) but don't actually have to go into orbit.

3.3 The Solar System

At the centre of the solar system is the star closest to Earth—the Sun. The Sun has the biggest effect on the space environment. As stars go, our Sun is quite ordinary. It's just one small, yellow star out of billions in the galaxy. Fuelled by nuclear fusion, it combines or "fuses" 600 million tons of hydrogen each second. We're most interested in two by-products of the fusion process

- Electromagnetic radiation
- Charged particles

The energy released by nuclear fusion is governed by Einstein's famous formula

$$E = mc^2$$

This energy, of course, makes life on Earth possible. And Sun produces lots of energy, enough each second to supply all the energy the United States needs for about 624 million years! This energy is primarily in the form of electromagnetic radiation. In a clear, blue sky, the Sun appears as an intensely bright circle of light. With your eyes closed on a summer day, you can feel the Sun's heat beating on you. But light and heat are only part of its *electromagnetic (EM) radiation*.

The term "radiation" often conjures up visions of nuclear wars and mutant space creatures, but EM radiation is something we live with every day. EM radiation is a way for energy to get from one place to another. We can think of the Sun's intense energy as radiating from its surface in all directions in waves. We classify these waves of radiant energy in terms of the distance between wave crests, or *wavelength*.

What difference does changing the wavelength make? If you've ever seen a rainbow on a sunny spring day, you've seen the awesome beauty of changing the wavelength of EM radiation by only 0.0000003 meters (9.8 $x10^{-7}$ ft.)! The colors of the rainbow, from violet to red, represent only a very small fraction of the entire electromagnetic spectrum. This spectrum spans from high energy X-rays (like you get in the dentist's office) at one end, to long-wavelength radio waves (like your favorite FM station) at the other. Light and all radiation move at the speed of light (300,000 km/s or more than 671 million m.p.h.). Solar radiation can be both helpful and harmful to spacecraft and humans in space.

The other fusion by-product we're concerned with is charged particles. Scientists model atoms with three building-block particles—protons, electrons, and neutrons, as illustrated in Figure19. Protons and electrons are *charged particles*. Protons have a positive charge, and electrons have a negative charge. The neutron, because it doesn't have a charge, is neutral. Protons and neutrons make up the nucleus or center of an atom. Electrons swirl around this dense nucleus. During fusion, the Sun's interior generates intense heat (more than 1,000,000° C). At these temperatures, a fourth state of matter exists. We're all familiar

with the other three states of matter—solid, liquid, and gas. If we take a block of ice (a solid) and heat it, we get water (a liquid). If we continue to heat the water, it begins to boil, and turns into steam (a gas). However, if we continue to heat the steam, we'd eventually get to a point where the water molecules begin to break down. Eventually, the atoms will break into their basic particles and form hot *plasma*. Thus, inside the Sun, we have a swirling hot soup of charged particles—free electrons and protons. (A neutron quickly decays into a proton plus an electron.) These charged particles in the Sun don't stay put. All charged particles respond to electric and magnetic fields. Your television set, for example, takes advantage of this by using a magnet to focus a beam of electrons at the screen to make it glow. Similarly, the Sun has an intense magnetic field, so electrons and protons shoot away from the Sun at speeds of 300
to 700 km/s (about 671,000 to 1,566,000 m.p.h.). This stream of charged particles flying off the Sun is called the *solar wind*.

Occasionally, areas of the Sun's surface erupt in gigantic bursts of charged particles called *solar particle events* or *solar flares* shown in Figure20, that make all of the nuclear weapons on Earth look like pop guns. Lasting only a few days or less, these flares are sometimes so violent they extend out to Earth's orbit (150 million km or 93 million mi.)! Fortunately, such large flares are infrequent (every few years or so) and concentrated in specific regions of space, so they usually miss Earth. Later, we'll see what kinds of problems these charged particles from the solar wind and solar flares pose to machines and humans in space. Besides the star of the show, the Sun, nine planets, dozens of moons, and thousands of asteroids are in our solar system (Figure21).

The planets range from the small terrestrial-class ones; Mercury, Venus, Earth, and Mars—to the mighty gas giants—Jupiter, Saturn, Uranus, and Neptune. Tiny Pluto is all alone at the edge of the solar system and may be a lost moon of Neptune.

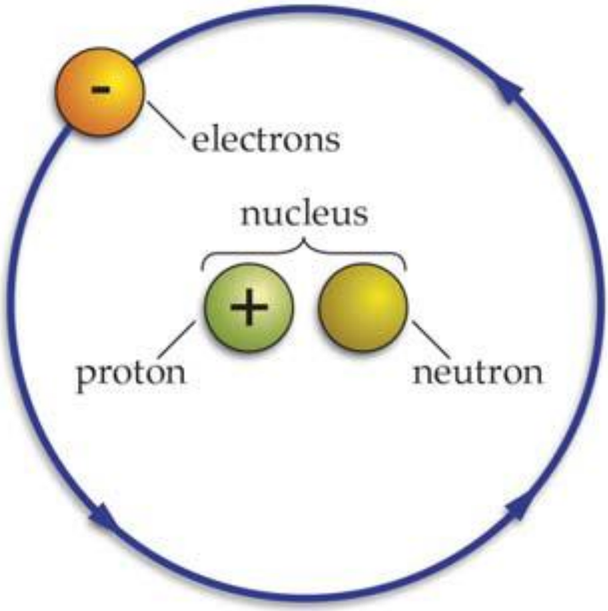

Figure19. The Atom.

The nucleus of an atom contains positively charged protons and neutral neutrons. Around the nucleus are negatively charged electrons.

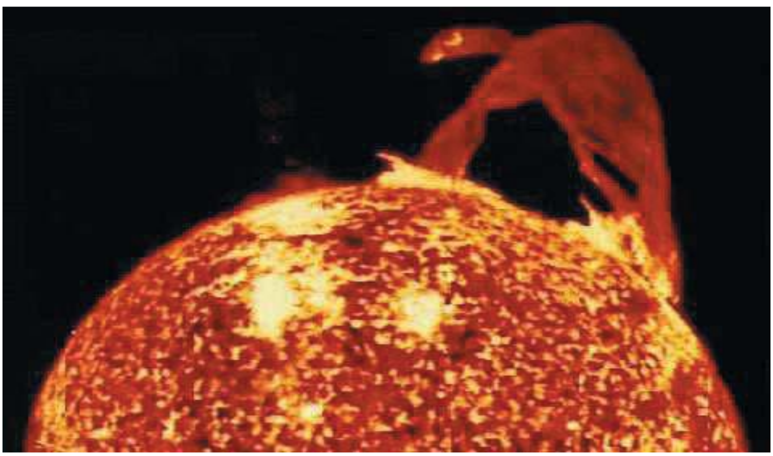

Figure20. Solar Flares: They fly out from the Sun long distances, at high speeds, and can disrupt radio signals on Earth, and disturb spacecraft orbits near Earth. *(Courtesy of NASA/Johnson Space Center)*

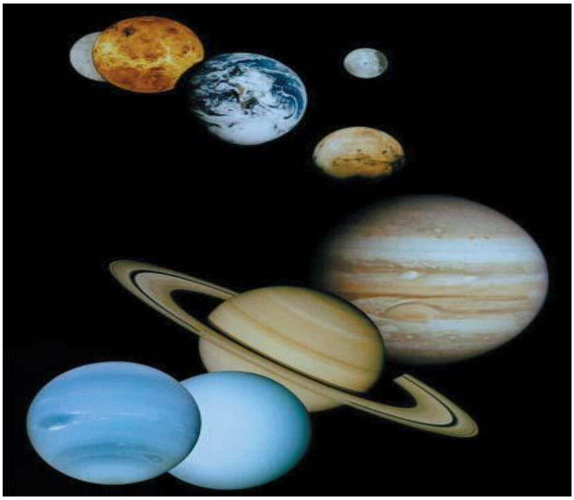

Figure21. Solar System.Nine planets and many other objects orbit the Sun, which holds the solar system together with its gravity. ***(Courtesy of NASA/Jet Propulsion Laboratory)***

If the Earth were the size of a baseball, about 10 cm (~4 in.) in diameter, the Moon would be only 2.54 cm (1 in.) in diameter and about 5.6 m (18 ft.) away. At the same scale the Sun would be a ball 10 m (33 ft.) in diameter (about the size and volume of a small two-bedroom house); it would be more than 2 km (nearly 1.3 mi.) away. Again, keeping the same scale, the smallest planet Pluto would be about the same size as Earth's Moon, 2.54 cm (1 in.), and 86.1 km (53.5 mi.) away from the house-sized Sun.

3.4The Cosmos

Space is big. Really BIG. Besides our Sun, more than 300 billion other stars are in our neighborhood—the Milky Way galaxy. Because the distances involved are so vast, normal human reckoning (kilometers or miles) loses meaning. When trying to understand the importance of charged particles in the grand scheme of the universe, for example, the mind boggles. Figure22-24tries to put human references on a scale with the other micro and macro dimensions of the universe. One convenient yardstick we use to discuss stellar distances is the light year. One *light year* is the distance light can travel in one year. At 300,000km/s, this is about 9.46 $x10^{12}$km (about 5.88 trillion mi.). Using this measure, we can begin to describe our location with respect to everything else in the universe.

The Milky Way galaxy is spiral shaped and is about 100,000 light years across. Our Sun and its solar system is about half way out from the center (about 25,000 light years) on one of the spiral arms. The Milky Way (and we along with it) slowly revolves around the galactic center, completing one revolution every 240 million years or so. The time it takes to revolve once around the center of the galaxy is sometimes called a *cosmic year*. In these terms, astronomers think our solar system is about 20 cosmic years old (4.8 billion Earth years). Stars in our galaxy are very spread out. The closest star to our solar system is Proxima Centauri at 4.22 light years or 4.0 $x10^{13}$km away. The Voyager spacecraft, currently moving at 56,400 km/hr. (35,000 m.p.h.), would take more than 80,000 years to get there! Trying to imagine these kinds of distances gives most of us a headache. The nearest galaxy to our own is Andromeda, which is about 2 million light years away. Beyond Andromeda are billions and billions of other galaxies, arranged in strange configurations which astronomers are only now beginning to catalog.

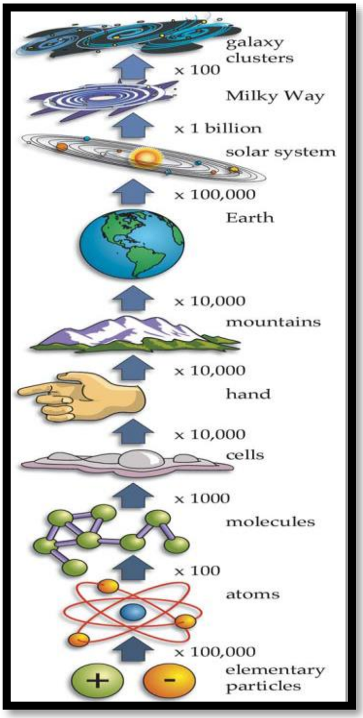

Figure22. From Micro to Macro.

To get an idea about the relative size of things inthe universe, start with elementary particles— protons and electrons. You can magnify them100,000 times to reach the size of an atom, etc.

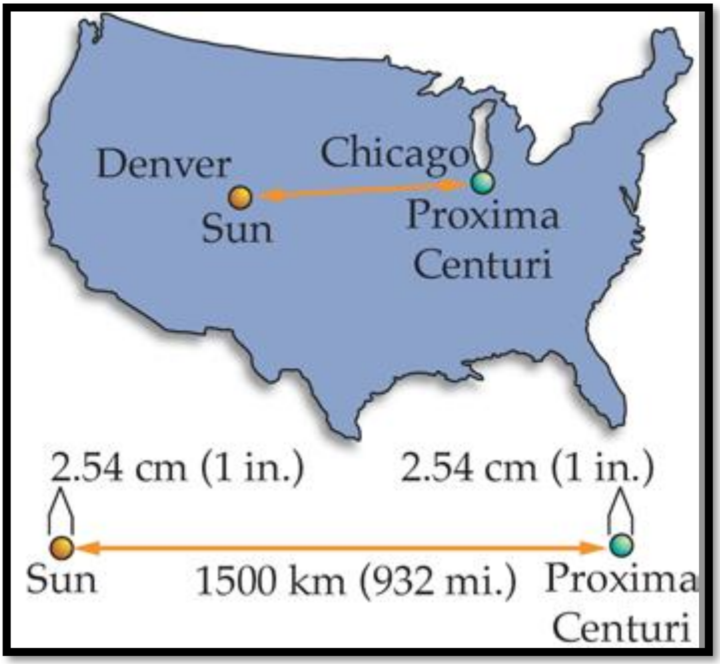

Figure23. Stellar Distances.

Let our Sun be the size of a large marble, roughly 2.54 cm (1 in.) in diameter. At this scale, the nearest star to our solar system, Proxima Centauri, would be more than 1500 km (932 mi.) away. So, if the Sun were the size of a large marble (2.54 cm or 1 in. in diameter) in Denver, Colorado, the nearest star would be in Chicago, Illinois. At this stellar scale, the diameter of the Milky Way galaxy would then be 33.8 million km (21 million mi.) across! Still too big for us to visualize!

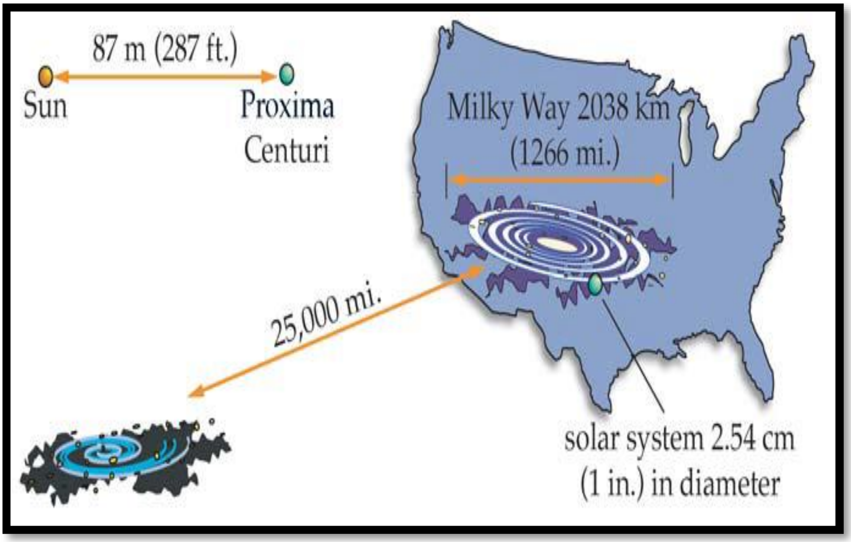

Figure 24. Galactic Distances.

Imagine the entire solar system ($7.3x10^9$ mi. across) were just the size of a large marble 2.54 cm (1 in.) in diameter. At this scale, the nearest star would be 87 m (287 ft.) away. The diameter of the Milky Way galaxy would then be 2038 km (1266 mi.). So, if the solar system were the size of a marble in Denver, Colorado, the Milky Way galaxy would cover most of the western United States. At this scale, the nearest galaxy would be 40,000 km (25,000 mi.) away.

3.5 SPACE ENVIRONMENT

There are 6 major environmental factors affect spacecraft in Earth orbit: Gravity, Micrometeoroids and space junk, Atmosphere, Radiation, Vacuum and Charged particles. Earth exerts a gravitational pull which keeps spacecraft in orbit. We best describe the condition of spacecraft and astronauts in orbit as free fall, because they're falling around Earth. Earth's atmosphere isn't completely absent in low-Earth orbit. It can cause Drag—which shortens orbit lifetime.

3.5.1 Gravity

Whenever we see astronauts on television floating around the Space Shuttle, as in Figure25, we often hear they are in "zero gravity." But this is not true! All objects attract each other with a gravitational force that depends on their mass (how much “stuff” they have). This force decreases as objects get farther away from each other, so gravity doesn’t just disappear once we get into space. In a low-Earth orbit, for example, say at an altitude of 300 km, the pull of gravity is still 91% of what it is on Earth’s surface. So why do astronauts float around in their spacecraft? A spacecraft and everything in it are in *free fall*. As the term implies, an object in free fall is falling under the influence of gravity, free from any other forces.

Free fall is that momentary feeling you get when you jump off a diving board. It’s what skydivers feel before their parachutes open. In free fall you don’t feel the force of gravity even though gravity is present. As you sit there in your chair, you don’t feel gravity on your behind. You feel the chair pushing up at you with a force equal to the force of gravity. Forces that act only on the surface of an object are *contact forces*. Astronauts in orbit experience no contact forces because they and their spacecraft are in free fall, not in contact with Earth’s surface. But if everything in orbit is falling, why doesn’t it hit Earth? An object in orbit has enough horizontal velocity so that, as it falls, it keeps missing Earth. Earth’s gravitational pull dominates objects close to it. But as spacecraft move into higher orbits, the gravitational pull of the Moon and Sun begin to exert their influence. For Earth-orbiting applications, we can assume the Moon and Sun have no effect. For interplanetary spacecraft, this assumption isn’t true—”the Sun’s gravitational pull dominates” for most of an interplanetary trajectory (the Moon has little effect on IP trajectories).

Gravity dictates the size and shape of a spacecraft’s orbit. Launch vehicles must first overcome gravity to fling spacecraft into space. Once a spacecraft is in orbit, gravity determines the amount of propellant its engines must use to move between orbits or link up with other spacecraft. Beyond Earth, the gravitational pull of the Moon, the Sun, and other planets similarly shape the spacecraft’s path. Gravity is so important to the space environment that an entire branch of astronautics, called *astrodynamics*, deals with quantifying its effects on spacecraft and planetary motion. The free-fall environment of space offers many potential opportunities for space manufacturing. On Earth, if we mix two materials, such as rocks and water, the heavier rocks sink to the bottom of the container. In free fall, we can mix materials that won't mix on Earth. Thus, we can make exotic and useful metal alloys for electronics and other applications, or new types of medicines.

However, free fall does have its drawbacks. One area of frustration for engineers is handling fluids in space. Think about the gas gauge in your car. By measuring the height of a floating bulb, you can constantly track the amount of fuel in the tank. But in orbit nothing "floats" in the tank because the liquid and everything else is sloshing around in free fall. Thus, fluids are much harder to measure (and pump) in free fall. But these problems are relatively minor compared to the profound physiological problems humans experience when exposed to free fall for long periods. We'll look at these problems separately in the next section.

Figure 25. Astronauts in Free Fall.

In the free-fall environment, astronauts Julie Payette (left) and Ellen Ochoa (STS-96) easily move supplies from the Shuttle Discovery to the Zarya module of the International Space Station. With no contact forces to slow them down, the supplies need only a gentle push to float smoothly to their new home. *(Courtesy of NASA/Johnson Space Center)*

3.5.2 Atmosphere

Earth's atmosphere affects a spacecraft in low-Earth orbit {below about 600 km (375 mi.) altitude}, in two ways:

• Drag—shortens orbital lifetimes
• Atomic oxygen—degrades spacecraft surfaces

Take a deep breath. The air you breathe makes up Earth's atmosphere. Without it, of course, we'd all die in a few minutes. While this atmosphere forms only a thin layer around Earth, spacecraft in low-Earth orbit can still feel its effects. Over time, it can work to drag a spacecraft back to Earth, and the oxygen in the atmosphere can wreak havoc on many spacecraft materials.

Two terms are important to understanding the atmosphere—pressure and density.

Atmospheric pressure represents the amount of force per unit area exerted by the weight of the atmosphere pushing on us.

Atmospheric density tells us how much air is packed into a given volume.

As we go higher into the atmosphere, the pressure and density begin to decrease at an ever-increasing rate. Visualize a column of air extending above us into space. As we go higher, there is less volume of air above us, so the pressure (and thus, the density) goes down. If we were to go up in an airplane with a pressure and density meter, we would see that as we go higher, the pressure and density begins to drop off more rapidly. Earth's atmosphere doesn't just end abruptly. Even at fairly high altitudes, up to 600 km (375 mi.), the atmosphere continues to create drag on orbiting spacecraft.

Drag is the force you feel pushing your hand backward when you stick it out the window of a car rushing along the freeway. The amount of drag you feel on your hand depends on the air'sdensity, your speed, the shape and size of your hand, and the orientation of your hand with respect to the airflow. Similarly, the drag on spacecraft in orbit depends on these same variables: the air's density plus the spacecraft's speed, shape, size, and orientation to the airflow. Drag immediately affects spacecraft returning to Earth. Drag quickly affects any spacecraft in a very low orbit (less than 130 km or 81 mi. altitude), pulling them back to a fiery encounter with the atmosphere in a few days or weeks. The effect of drag on spacecraft in higher orbits is much more variable. Between 130 km and 600 km (81 mi. and 375 mi.), it will vary greatly depending on how the atmosphere changes (expands or contracts) due to variations in solar activity. Acting over months or years, drag can cause spacecraft in these orbits to gradually lose altitude until they re-enter the atmosphere and burn up. In 1979, the Skylab space station succumbed to the long-term effects of drag and plunged back to Earth. Above 600 km (375 mi.), the atmosphere is so thin the drag effect is almost insignificant. Thus, spacecraft in orbits above 600 km are fairly safe from drag. Besides drag, we must also consider the nature of air. At sea level, air is about 21% oxygen, 78% nitrogen, and 1% miscellaneous other gasses, such as argon and carbon dioxide. Normally, oxygen atoms like to hang out in groups of two--molecules, abbreviated O_2. Under normal conditions, when an oxygen molecule splits apart for any reason, the atoms quickly reform into a new molecule. In the upper parts of the atmosphere, oxygen molecules are few and far between. When radiation and charged particles cause them to split apart, they're sometimes left by themselves as *atomic oxygen*, abbreviated O. So what's the problem with Oxygen? We've all seen the results of exposing a piece of steel outside for a few months or years—it starts to rust. Chemically speaking, rust is *Oxidation.* It occurs when oxygen molecules in the air combine with the metal creating an oxide-rust. This oxidation problem is bad enough with O_2, but when O by itself is present, the reaction is much, much worse. Spacecraft materials exposed to atomic oxygen experience breakdown or "rusting" of their surfaces, which can eventually weaken components, change their thermal characteristics, and degrade sensor performance. On the good side, most atomic oxygen floating around in the upper atmosphere combines with oxygen molecules to form a special molecule, O_3, called *ozone*. Ozone acts like a window shade to block harmful radiation, especially the ultraviolet radiation that causes sunburn and skin cancer.

3.5.3 Vacuum

Beyond the thin skin of Earth's atmosphere, we enter the vacuum of space. This vacuum environment creates three potential problems for spacecraft, namely;

• Out-gassing—release of gasses from spacecraft materials
• Cold welding—fusing together of metal components
• Heat transfer—limited to radiation

As we've seen, atmospheric density decreases dramatically with altitude. At a height of about 80 km (50 mi.), particle density is 10,000 times less than what it is at sea level. If we go to 960 km (596 mi.), we would find a given volume of space to contain one trillion times less air than at the surface. A pure vacuum, by the strictest definition of the word, is a volume of space completely devoid of all material. In practice, however, a pure vacuum is nearly unattainable. Even at an altitude of 960 km (596 mi.), we still find about 1,000,000 particles per cubic centimeter. So when we talk about the vacuum of space, we're talking about a "near" or "hard" vacuum. Under standard atmospheric pressure at sea level, air exerts more than 101,325 N/m^2 of force on everything it touches. The soda inside a soda can is under slightly higher pressure, forcing carbon dioxide (CO_2) into the solution. When you open the can, you release the pressure, causing some of the $CO_2$to come out of the solution, making it foam. Spacecraft face a similar, but less tasty, problem. Some materials used in their construction, especially composites, such as graphite/epoxy, can trap tiny bubbles of gas while under atmospheric pressure. When this pressure is released in the vacuum of space, the gasses begin to escape. This release of trapped gasses in a vacuum is called *out-gassing*. Usually, out -gassing is not a big problem; however, in some cases, the gasses can coat delicate sensors, such as lenses or cause electronic components to arc, damaging them. When this happens, out-gassing can be destructive.

Another problem created by vacuum is cold welding. *Cold welding* occurs between mechanical parts that have very little separation between them. When we test the moving part on Earth, a tiny air space may allow the parts to move freely. After launch, the hard vacuum in space eliminates this tiny air space, causing the two parts to effectively “weld” together. When this happens, ground controllers must try various techniques to “unstick” the two parts. For example, they may expose one part to the Sun and the other to shade so that differential heating causes the parts to expand and contract, respectively, allowing them to separate. Due to cold welding, as well as practical concerns about mechanical failure, spacecraft designers carefully try to avoid the use of moving parts. However, in some cases, such as with spinning wheels used to control spacecraft attitude, there is no choice. On Earth, moving parts, like you find in your car engine, are protected by lubricants such as oil. Similarly, spacecraft components sometimes need lubrication. However, because of the surrounding vacuum, we must select these lubricants carefully, so they don’t evaporate or outgas. Dry graphite (the “lead” in your pencil) is an effective lubricant because it lubricates well and won’t evaporate into the vacuum as common oil would.

Finally, the vacuum environment creates a problem with heat transfer. Heat gets from one place to another in three ways:

- *Conduction*

This is heat flow directly from one point to another through a medium (solid). If you hold a piece of metal in a fire long enough, you’ll quickly discover how conduction works when it burns your fingers.

The second method of heat transfer is convection.

- *Convection*

This takes place when gravity, wind, or some other force moves a liquid or gas over a hot surface. Heat transfers from the surface to the fluid. Convection takes place whenever we feel chilled by a breeze or boil water on the stove. Astronauts can use both of these methods to move heat around inside a spacecraft but not to remove heat from a spacecraft in the free fall, vacuum environment of space.

The third method is radiation.

- *Radiation*

This is a way to transfer energy from one point to another. The heat you feel coming from the glowing coils of a space heater is radiated heat. Because radiation doesn't need a solid or fluid medium, it's the primary method of moving heat into and out of a spacecraft.

4.0 SELF ASSESSMENT EXERCISE

Discuss what you understand by Space environment.

5.0 CONCLUSION

We have learnt that space begins at an altitude where a satellite can briefly maintain an orbit. Thus, space is close. It's only about 130 km (81 mi.) straight up.

6.0 SUMMARY

We have learnt that:

- Space is a place where spacecraft orbit Earth, planets orbit the Sun, and the Sun revolves around the centre of our galaxy.
- The Sun has the biggest effect on the space environment.
- The energy released by nuclear fusion is governed by Einstein's famous formula $E = mc^2$
- The planets range from the small terrestrial-class ones; Mercury, Venus, Earth, and Mars—to the mighty gas giants—Jupiter, Saturn, Uranus, and Neptune. Tiny Pluto is all alone at the edge of the solar system and may be a lost moon of Neptune.
- Six major environmental factors affect spacecraft in Earth orbit:Gravity, Micrometeoroids and space junk, Atmosphere, Radiation, Vacuum and Charged particles.
- Spacecraft can experience out-gassing—a condition in which a material releases trapped gas particles when the atmospheric pressure drops to near zero.
- Cold welding—a condition that can cause metal parts to fuse together.
- Radiation, primarily from the Sun, can cause heating on exposed surfaces, damage to electronic components and disruption in communication.

7.0 TUTOR MARKED ASSIGNMENT (TMA)

i. Explain the following terms

a. Conduction
b. Convection
c. Radiation

ii. Explain the Primary method of moving heat into and out of a spacecraft.

iii. Differentiate between Atmospheric Pressure and Atmospheric Density.

iv. Explain the following sources of Charged particles

a. Solar wind and flares
b. Galactic cosmic rays (GCRs)
c. Van Allen radiation belts

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MODULE 3 ROCKET ENGINEERING, SPACE EXPLORATION & SPACE LAW

Unit1 Rocket Engineering

1.1.1 Principles of rocket propulsion
1.1.2 Thermal Rockets

Unit 2The Rotation of the earth

1.1.3 Rotation of the earth
1.1.4 Orbits & spaceflight

Unit 3 introduction to Cosmology

1.1.5 Fundamental observations of modern cosmology
1.1.6 Evolution of cosmological theories

Unit 4 Modern Cosmology

1.1.7 Modern cosmology
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Unit 5 Space Law

1.1.9 International law
1.1.10 Space treaties

UNIT 1 ROCKET ENGINEERING

CONTENTS

1.0 INTRODUCTION

A Rocket is a self-propelled device that carries its own fuel, as well as the oxygen, or other chemical agent, needed to burn its fuel. Most rockets move by burning their fuel and expelling the hot exhaust gases that result. The force of these hot gases shooting out in one direction causes the rocket to move in the opposite direction. A rocket engine is the most powerful engine for its weight.

2.0 OBJECTIVES

At the end of this unit the reader should be able to:

- Define a Rocket.
- Explain the Principles of Rocket propulsion.
- State the Newton's third law of motion and derive the Rocket equation.
- Explain the Tsiolkovsky's rocket equation.
- Explain the principles of the thermal Rocket.

3.0 MAIN CONTENT

3.1 Principles of Rocket propulsion

Human development has always been closely linked with transportation. The domestication of the horse and the invention of the wheel had a dramatic effect on early civilization. Most of the past millennium has been strongly influenced by sailing ship technology, both for war and commerce; in the twentieth century, motor vehicles and aircraft have revolutionized transport. At the beginning of the twenty-first century the rocket may be seen as the emerging revolution in transport. So far, only a few humans have actually travelled in rocket-propelled vehicles, but a surprising amount of commercial and domestic communication is now reliant on satellites. From telephone calls, through news images, to the Internet, most of our information travels from one part of the world to another, through space. The proposed return to the Moon and new plans to send humans to Mars indicate a resurgence of interest in space exploration for the new millennium.

Rocket propulsion is the essential transportation technology for this rapid growth in human communication and exploration. From its beginnings in ancient China through its rapid development during the Cold War, rocket propulsion has become the essential technology of the late twentieth century. It influences the lives and work of a growing number of people, who may wish to understand at least the principles behind it and its technical limitations. In most cases, users of space transportation are separated from the rocket technology which enables it; this is partly because of the mass of engineering detail and calculation which is essential to make such a complex system work. In what follows, we shall attempt to present the basic principles, and describe some of the engineering detail, in a way that exposes the essentialphysicsandthereallimitationstotheperformanceofrocketv ehicles.

In its basic form, a rocket is a device which propels itself by emitting a jet of matter. The momentum carried away by the jet results in a force, acting so as to accelerate the rocket in the direction opposite to that of the jet. The essential facts are that the rocket accelerates, and its mass decreases. In gunnery, propulsion is very different.

All the energy of a cannon ball is given to it in the barrel of the gun by the expansion of the hot gases produced by the explosion of the gunpowder. Once it leaves the barrel, its energy and its velocity begin to decrease, because of air friction or drag. The rocket, on the other hand, experiences a continuous propulsive force, so its flight will be different from that of a cannon ball. Infact,while the cannon ball is a *projectile*, the rocket is really a *vehicle*.

Newton's Third Law and the Rocket Equation

As we have seen, the rocket had been a practical device for more than 1,000 years before Tsiolkovsky determined the dynamics that explained its motion. In doing so, he opened the way to the use of the rocket as something other than an artillery weapon of dubious accuracy. In fact, he identified the rocket as the means by which humanity could explore space.

This was revolutionary: earlier, fictitious journeys to the Moon had made use of birds or guns as the motive force, and rockets had been discounted. By solving the equation of motion of the rocket, Tsiolkovsky was able to show that space travel *was* possible, and that it could be achieved using a device which was readily to hand, and only needed to be scaled up. He even identified the limitations and design issues which would have to be faced in realising a practical space vehicle.

The dynamics are so simple that it is surprising that it had not been solved before, but this was probably due to a lack of interest: perusal of dynamics books of the period reveals consistent interest in the flight of unpowered projectiles, immediately applicable to gunnery.

In its basic form, a rocket is a device which propels itself by emitting a jet of matter. The momentum carried away by the jet

results in a force, acting so as to accelerate the rocket in the direction opposite to that of the jet. This is familiar to us all, from games with deflating toy balloons, if nothing else. The essential facts are that the rocket accelerates, and its mass decreases; the latter is not so obvious with a toy balloon, but is nevertheless true.

In gunnery, propulsion is very different. All the energy of a cannon ball is given to it in the barrel of the gun by the expansion of the hot gases produced by the explosion of the gunpowder. Once it leaves the barrel, its energy and its velocity begin to decrease, because of air friction or drag. The rocket, on the other hand, experiences a continuous propulsive force, so its flight will be different from that of a cannon ball. In fact, while the cannon ball is a *projectile*, the rocket is really a *vehicle*. The Boston Gun Club cannon, in Jules Verne's novel, was in fact the wrong method. To get to the Moon, or indeed into Earth orbit, requires changes in speed and direction, and such changes cannot be realised with a projectile. H. G. Wells' *cavorite*-propelled vehicle was closer to the mark.

Tsiolkovsky's rocket equation

Tsiolkovsky was faced with the dynamics of a vehicle, the mass of which is decreasing as a jet of matter is projected rearwards. As we shall see later, the force that projects the exhaust is the same force that propels the rocket. It partakes in Newton's third law ‘action and reaction are equal and opposite', where 'action ‘means force. The accelerating force is represented, using Newton's law, as

$$F = mv_e$$

In this equation, the thrust of the rocket is expressed interms of the *mass flow rate*, *m*, and the *effective exhaust velocity*, v_e.

So the energy released by the burning propellant appears as a fast-moving jet of matter, *and* a rocket accelerating in the opposite direction. Newton's law can be applied to this dynamical system, and the decreasing mass can be taken into account, using some simple differential calculus. The resultant formula which

Tsiolkovsky obtained for the vehicle velocity *v* is simple and revealing:

$$\boldsymbol{V = v_e log_e \frac{M_0}{M}}$$

Here $M_0$is the mass of the rocket at ignition, and *M* is the current mass of the rocket. The only other parameter to enter into the formula is v_e, the effective exhaust velocity. This simple formula is the basis of all rocket propulsion. The velocity increases with time as the propellant is burned. It depends on the natural logarithm of the ratio of initial to current mass; that is, on how much of the propellant has been burned. For a fixed amount of propellant burned, it also depends on the exhaust velocity and how fast the mass is being expelled.

The mass ratio, often written as *R*, or A, is just the ratio of the initial mass M_0 to the current mass M:

$$R = \frac{M_0}{M}$$

In most cases, the final velocity of the rocket needs to be known, and here the appropriate value is the mass ratio when all the fuel is exhausted. Unless otherwise stated, the final mass ratio should be assumed.

The rocket equation shows that the final speed depends upon only two numbers: the final mass ratio, and the exhaust velocity. It does not depend on the thrust, rather surprisingly, or the size of the rocket engine, or the time the rocket burns, or any other parameter. Clearly, a higher exhaust velocity produces a higher rocket velocity, and much of the effort in rocket design goes into increasing the exhaust velocity. Gunpowder, and the range of propellants used for nineteenth century rockets, produced an exhaust velocity around 2,000 ms^{-1}, or a little more. The most advanced liquid-fuelled chemical rockets today produce an exhaust velocity of, at best, 4,500 ms^{-1}.There is nowhere else to go :this is close to the theoretical limit of chemical energy extraction.

To achieve a high rocket velocity, the mass ratio has to be large. The mass ratio is defined as the ratio of vehicle-plus-propellant mass, to vehicle mass. In these terms, a mass ratio of, say, 5 indicates that 80% of the initial mass of the rocket is fuel. This is very different from a car, for instance, which has a typical empty mass of 1.5 tonnes, and a fuel mass of 40kg; amass ratioof1.003.Soarocketvehicleisnothinglikeany other kind of vehicle, because of the requirement to have a mass ratio considerably greater than 1.

It is as well to mention here that a rocket carries both its fuel and its oxidiser, and needs no intake of air to operate, like, for example, a jet engine. It can therefore function in a vacuum and in fact works better, because air pressure retards the exhaust and reduces the thrust. It also works, rather inefficiently, under water, provided that the combustion chamber pressure exceeds the hydrostatic pressure; those who have cast a weighted firework into water can vouch for this.

3.2 The Thermal Rocket

The rocket principle is the basis of all propulsion in space, and all launch vehicles. The twin properties of needing no external medium for the propulsion system to act upon, and no external oxidant for the fuel, enable rockets to work in any ambient conditions, including the vacuum of space.

The thermal rocket is the basis of all launchers, and almost all space propulsion (although some electric propulsion uses a different principle). The thermal rocket motor is a heat engine: it converts the heat, generated by burning the propellants fuel and oxidizer, in the combustion chamber and into energy of the emerging exhaust gas.

The momentum carried away by the exhaust gas provides the thrust, which accelerates the rocket. As a heat engine, the rocket is no different in principle from other heat engines, such as the steam engine or the internal combustion engine. The conversion of heat into work is the same, whether the work is done on a piston, or on a stream of exhaust gas.

The basic configuration of the thermal rocket

A liquid-fuelled rocket engine consists of a combustion chamber into which fuel and oxidant are pumped, and an expansion nozzle which converts the high-pressure hot gas, produced by the combustion, into a high velocity exhaust stream. It is the expansion

of the hot gas against the walls of the nozzle which does work and accelerates the rocket.

A solid-fuelled motor operates in the same way, except that the fuel and oxidant are pre-mixed in solid form, and are contained within the combustion chamber. Normally the combustion takes place on the inner surface of the propellant charge. The exhaust nozzle is identical in form to that in the liquid-fuelled motor, and the principles of operation are the same. In this module, we shall make little distinction between the solid- and liquid-fuelled variants of the thermal rocket motor (Figure26).

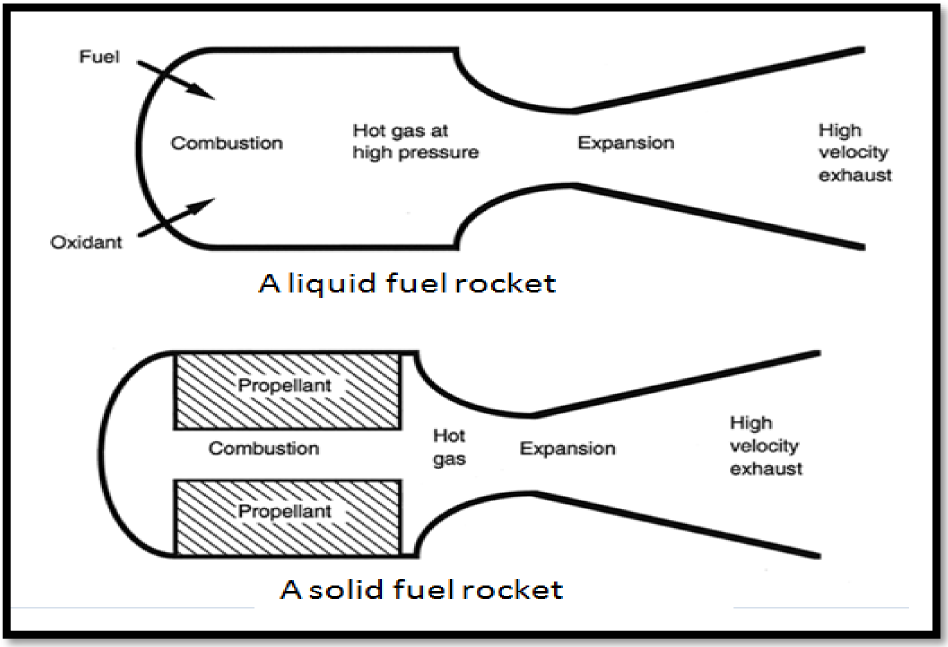

Figure26. Liquid and solid fuel rockets

4.0 SELF ASSESSMENT EXERCISE

Briefly discuss the principles of rocket propulsion.

5.0 CONCLUSION

We have learnt that Rocket propelled vehicles are the essential transportation technology for this rapid growth in human communication and exploration. Additionally, the thermal rocket is the basis of all launchers, and almost all space propulsion.

6.0 SUMMARY

We have learnt that:

- A rocket is a device which propels itself by emitting a jet of matter. The momentum carried away by the jet results in a force, acting so as to accelerate the rocket in the direction opposite to that of the jet.

- A rocket carries both its fuel and its oxidiser, and needs no intake of air to operate.
- A rocket can function in a vacuum and in fact works better, because air pressure retards the exhaust and reduces the thrust.
- The rocket principle is the basis of all propulsion in space, and all launch vehicles.
- The thermal rocket motor is a heat engine: it converts the heat, generated by burning the propellants fuel and oxidizer, in the combustion chamber and into energy of the emerging exhaust gas.
- A liquid-fuelled rocket engine consists of a combustion chamber into which fuel and oxidant are pumped, and an expansion nozzle which converts the high-pressure hot gas, produced by the combustion, into a high velocity exhaust stream.

7.0 TUTOR MARKED ASSIGNMENT

i. Discuss the principles of Rocket propulsion.

ii. State the 3rd Newton's law of motion.

iii. a. What is Orbit?

b. How does the Thermal Rocket engine works?

iv. Write and explain the Tsiolkovsky rocket equation.

v. Differentiate between the cannon ball and the rocket.

vi. Derive the equation $h = Mr_0V_0$ showing that the orbit depends only on the initial velocity and the distance from the centre of the Earth.

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UNIT2 ROTATION OF THE EARTH

CONTENTS

1.0 INTRODUCTION

In an isolated system, the amount of rotation or revolution, known as angular momentum, doesn't change. The angular momentum of a rotating object depends on its speed of rotation, its mass, and the distance of the mass from the axis. Thus when an ice skater draws his or her arms in, thereby bringing the distribution of mass closer to the center, the skater spins faster. The amount of angular momentum is conserved. The speed of Earth's rotation is best measured by studying historical records of eclipses. A total solar eclipse is so dramatic that even written descriptions from thousands of years ago can be interpreted to show whether a total eclipse occurred at the writer's location. A slowing Earth shifts the positions affected by a total solar eclipse on Earth's surface. In the Earth-Moon system, the tidal bulge goes around faster than the Moon's gravity would make it revolve, because the Earth is rotating. That tidal bulge pulls on the Moon, speeding up its revolution around Earth and making it go farther out. This is due to Newton's third law of motion, which states that an object experiences a force because it is interacting with some other object. Thus, even the weaker object exerts some force over the stronger one.

9.0 OBJECTIVES

At the end of this unit the reader should be able to:

- Explain the earth's rotation.
- Explain how a spacecraft gets into space.
- Define Parking Orbit.
- Show how to calculate the path of the spacecraft in terms of the total angular momentum.

1.0 MAIN CONTENT

3.1 Orbits and Spaceflight

Leaving the problems of exhaust velocity and mass ratio for a moment, we shall turn, with Tsiolkovsky, to the question of how to get into space. This involves gravity, and the motion of vehicles in the Earth's gravitational field. Common experience, with a cricket ball for example, tells us that the faster a body is projected upwards, the further it goes.

The science of ballistics tells us that a shell, with a certain velocity, will travel furthest in a horizontal direction, if projected at an initial angle of 45^{o}. The equations of motion of a cricket ball, or a shell, can be solved using a constant and uniform gravitational field, with very little error. This is a matter for school physics. When we consider space travel, the true shape of the gravitational field becomes important: it is a radial field, with its origin in the centre of the Earth. Note that the gravitational field of a spherical object is accurately represented by assuming that it acts from the centre, with the full mass of the object. The flat Earth approximation is good enough for distances travelled which are small compared with the curvature of the Earth, but cannot be applied to space travel, where the distances are much greater.

The path of a ball may appear to be a parabola which begins and ends on the surface of the Earth, but in reality it is a segment of an ellipse with one focus at the centre of the Earth. If one imagines the Earth to be transparent to matter, then the ball would continue through the impact point, down past the centre of the Earth, and return upwards to pass through the point from which it was thrown. Without the drag caused by the atmosphere and by the solid Earth, it would continue to move in an elliptical orbit forever. Of course, the Earth would continue to rotate, so the points where the orbit passes through the surface would change for each cycle. This latter point is important to remember: a body moving in an orbit does not 'see' the rotation of the Earth; we do not notice this for normal projectiles, but it is important for rocket launches.

Orbits

Having introduced the topic of orbits we can now look into the motion of spacecraft, which always move in orbits and not in straight lines. Gravity cannot be turned off. A spacecraft does not 'leave' the Earth's gravity; it would be more correct to say that it 'gives in' to the Earth's gravity. So the motion of a spacecraft is that of a body, with a certain momentum, in a central gravitational field.

The path of the spacecraft can be calculated in terms of the total angular momentum it has in its orbit, which is a constant. The other defining parameter is the minimum distance of the orbit from its focus to the centre of the Earth.

The way to think of this is to imagine a spacecraft stationary at a certain altitude. The rocket fires, and gives it a certain velocity V, tangential to the gravitational field (parallel to the surface of the Earth). The kinetic energy of the spacecraft will be MV^2; and its momentum and angular momentum about the centre of the Earth will be MV and MrV respectively. Here r is the distance from the

centre of the Earth, not just the height above the surface.
The spacecraft moves under the combined effects of its momentum, given by the rocket, and the attraction of gravity towards the centre of the Earth. It will move in a curved path that can be represented by an equation of motion, and its solution. The solution to the equation of motion gives the radius *r*, of the orbit and the current distance of the spacecraft from the centre of the Earth, as a function of the angle made by the current radius vector to that of closest approach. This is the angle between *r* and $r0$ in Figure 1.7. As time elapses the spacecraft will travel along the curve shown, initially becoming further from the Earth, while the angle increases. The expression for the path is:

$$\frac{1}{r} = \frac{GM_eM^2}{h^2}(1 + c\ cos0)$$

The mass of the Earth is represented by Me, *h* is the (constant) angular momentum, and *c* is the eccentricity of the orbit. The eccentricity defines the shape of the orbit. For an ellipse, *c* is the ratio of the distance between the foci, to the length of the major axis. For a circle, in which the foci coincide, *c* becomes equal to zero. In order to understand how the orbit varies with the initial velocity of the spacecraft, the angular momentum and the eccentricity have to be expressed in terms of useful parameters. They are given by the following formulae:

$$h = MrV$$

$$c = \frac{h^2}{GM_eM^2r_0} - 1$$

Since *h* is constant throughout the orbit, it can be evaluated at the most convenient point (where the radius is at a minimum), and we know the velocity. This is just the initial velocity given to the spacecraft by the rocket. So

$$h = Mr_0V_0$$

Where V_0 is the initial velocity. Having fixed values for the initial radius and velocity, we can see that both the angular momentum and the eccentricity are fixed. Thus, the shape of the orbit depends only on the initial velocity and the distance from the centre of the Earth.

4.0 SELF ASSESSMENT EXERCISE

How does the rotation of the earth affect the velocity of Satellites?

5.0 CONCLUSION

We have learnt that if the satellite travels in an east-west direction, then the speed is subtracted. If the orbit is at right angles to the equator, and the satellite travels over the poles, then the rotation speed of the Earth has no effect.

6.0 SUMMARY

We have learnt that:

- The rotation of the Earth has no affect on the motion of an orbiting satellite.
- The velocity of rotation of the Earth's surfaceatthelaunchsiteaddsalgebraicallytothevelocityofth esatellite.Theeffect of this depends on the inclination of the orbit and the direction of motion of the satellite in its orbit
- The flat Earth approximation is good enough for distances travelled which are small compared with the curvature of the Earth, but cannot be applied to space travel, where the distances are much greater.
- The angular momentum of space crafts is given by

$$\boldsymbol{h = MrV}$$

7.0 TUTOR MARKED ASSIGNMENT

1. Derive the equation $h = Mr_0V_0$ showing that the orbit depends only on the initial velocity and the distance from the centre of the Earth.

2. Discuss how the rotation of the earth affects the velocity of Satellites.

3. Define the following
a. Centrifugal force
b. Centripetal force

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UNIT 3 INTRODUCTION TO COSMOLOGY

CONTENTS

1.0 Introduction

2.0 Objectives

3.0 Main Content

3.1 Fundamental observations of modern cosmology

3.2 Evolution of Cosmological Theories

4.0 Self Assessment Exercise

5.0 Conclusion

6.0 Summary

7.0 Tutor Marked Assignment

8.0 Reference/Further Reading

1.0 INTRODUCTION

Cosmology is the study of the universe as a whole, including its distant past and its future. Cosmologists study the universe by observing, by looking at the universe and theoretically by using physical laws and theories to predict how the universe should behave. Cosmology is a branch of astronomy, but the observational and theoretical techniques used by cosmologists involve a wide range of other sciences, such as physics and chemistry.

2.0 OBJECTIVES

At the end of this unit the reader should be able to:

- Explain the Fundamental observations of modern cosmology.
- List and explain the Evolution of Cosmological theories.
- Explain when the universe is isotropic andhomogeneous.
- Should be able to show that The intensity of radiation from the shell of stars (that is, the power per unit area per steradian of the sky) is given by

$$dJ = \frac{nL}{4\pi} dr$$

3.0 MAIN CONTENT

3.1 FUNDAMENTAL OBSERVATIONS OF MODERN COSMOLOGY

Cosmology is the study of the universe, or cosmos, regarded as a whole. At- tempting to cover the study of the entire universe in a single volume may seem like a megalomaniac's dream. The universe, after all, is richly textured, with structures on a vast range of scales; planets orbit stars are collected into galaxies, galaxies are gravitationally bound into clusters, and even clusters of galaxies are found within larger superclusters. Given the richness and complexity of the universe, the only way to condense its history into a single book is by a process of ruthless simplification. For much of this book, therefore, we will be considering the properties of an idealized, perfectly smooth, model universe. Only near the end of the book will we consider how relatively small objects, such as galaxies, clusters, and su- perclusters, are formed as the universe evolves. It is amusing to note, in this context, that the words "cosmology" and "cosmetology" come from the same Greek root: the word "kosmos", meaning *harmony* or *order*. Just as cosmetologists try to make a human face more harmonious by smoothing over small blemishes such as pimples and wrinkles, cosmologists sometimes must smooth over small “blemishes” such as galaxies.

A science which regards entire galaxies as being small objects might seem, at first glance, very remote from the concerns of humanity. Nevertheless, cosmology deals with questions which are fundamental to the human condition. The questions which vex humanity are “Where do we come from? What are we? Where are we going?” Cosmology grapples with these questions by describing the past, explaining the present, and predicting the future of the universe. Cosmologists ask questions such as “What is the universe made of? Is it finite or infinite in spatial extent? Did it have a beginning sometime in the past? Will it come to an end sometime in the future?”

Cosmology deals with distances that are very large, objects that are very big, and timescales that are very long. Cosmologists frequently find that the standard SI units are not convenient for their purposes: the meter (m) is awkwardly short, the kilogram (kg) is awkwardly tiny, and the second (s) is awkwardly brief. Fortunately, we can adopt the units which have been developed by astronomers for dealing with large distances, masses, and times.

One distance unit used by astronomers is the astronomical unit (AU), equal to the mean distance between the Earth and Sun; in metric units, 1 AU = 1.5×10^{11} m. Although the astronomical unit is a useful length scale within the Solar System, it is small compared to the distances between stars.

To measure interstellar distances, it is useful to use the parsec (pc), equal to the distance at which 1 AU subtends an angle of 1 arc second; in metric units, 1pc = 3.1×10^{16} m. For example, we are at a distance of 1.3 pc from Proximal Centauri (the Sun’s nearest neighbor among the stars) and 8500 pc from the center of our Galaxy. Although the parsec is a useful length scale within our Galaxy, it is small compared to the distances between galaxies. To measure intergalactic distances, it is useful to use the mega parsec

(Mpc), equal to 10^6 pc, or 3.1x 10^{22} m. For example, we are at a distance of 0.7 Mpc (otherwise known as the Andromeda galaxy) and 15 Mpc from the Virgo cluster (the nearest big cluster of galaxies).

The standard unit of mass used by astronomers is the solar mass (M_0); in metric units, the Sun's mass is $1 M_0 = 2.0 \times 10^{30}$ kg. One distance unit used by astronomers is the astronomical unit (AU), equal to the mean distance between the Earth and Sun; in metric units, $1 \text{ AU} = 1.5 \text{ x} 10^{11}$ m. Although the astronomical unit is a useful length scale within the Solar System, it is small compared to the distances between stars.

To measure interstellar distances, it is useful to use the parsec (pc), equal to the distance at which 1 AU subtends an angle of 1 arc second; in metric units, 1 pc = 3.1 x10^{16} m. For example, we are at a distance of 1.3 pc from Proxima Centauri (the Sun's nearest neighbor among the stars) and 8500 pc from the center of our Galaxy. Although the parsec is a useful length scale within our Galaxy, it is small compared to the distances between galaxies. To measure intergalactic distances, it is useful to use the megaparsec (Mpc), equal to 10^6 pc, or 3.1x10^{22} m. For example, we are at a distance of 0.7 Mpc from M31 (otherwise known as the Andromeda galaxy) and 15 Mpc from the Virgo cluster (the nearest big cluster of galaxies). The standard unit of mass used by astronomers is the solar mass (M_0); in metric units, the Sun's mass is $1 M_0 = 2.0 \times 10^{30}$ kg. The total mass of our Galaxy is not known as accurately as the mass of the Sun; in round numbers, though, it is $M_{gal} \approx 10^{12} M_0$. The Sun, incidentally, also provides the standard unit of power used in astronomy. The Sun's luminosity (that is, the rate at which it radiates away energy in the form of light) is $1 L_0 = 3.8 \times 10^{26}$ watts. The total luminosity of our Galaxy is $L_{gal} = 3.6 \times 10^{10} L_0$.

Some of the observations on which modern cosmology is based are highly complex, requiring elaborate apparatus and sophisticated data analysis. However, other observations are surprisingly simple. Let's start with an observation which is deceptive in its extreme simplicity.

❖ The night sky is dark

Step outside on a clear, moonless night, far from city lights, and look upward. You will see a dark sky, with roughly two thousand stars scattered across it. The fact that the night sky is dark at visible wavelengths, instead of being uniformly bright with starlight, is known as *Olbers' Paradox,* after the astronomer Heinrich Olbers, who wrote a scientific paper on the subject in the year 1826. As it happens, Olbers was not the first person to think about Olbers' Paradox. As early as 1576, Thomas Digges mentioned how strange it is that the night sky is dark, with only a few pinpoints of light to mark the location of stars.

Why should it be paradoxical that the night sky is dark? Most of us simply take for granted the fact that daytime is bright and nighttime is dark. The darkness of the night sky certainly posed no problems to the ancient Egyptians or Greeks, to whom stars were points of light stuck to a dome or sphere. However, the cosmological model of Copernicus required that the distance to stars be very much larger than an astronomical unit; otherwise, the parallax of the stars, as the Earth goes around on its orbit, would be large enough to see with the naked eye. Moreover, since the Copernican system no longer requires that the stars be attached to a rotating celestial sphere, the stars can be at different distances from the Sun. These liberating realizations led Thomas Digges, and other post-Copernican astronomers, to embrace a model in which stars are large glowing spheres, like the Sun, scattered throughout infinite space.

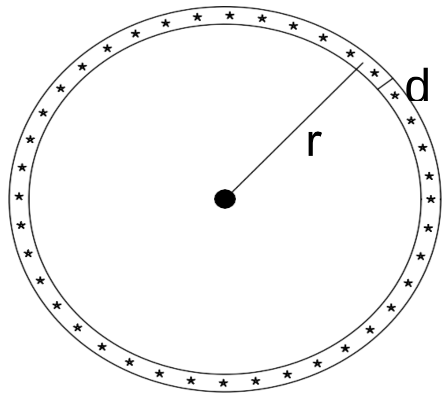

Figure1.31: A star-filled spherical shell, of radius *r* and thickness *dr*, centered on the Earth.

Let's compute how bright we expect the night sky to be in an infinite universe. Let *n* be the average number density of stars in the universe, and let *L* be the average stellar luminosity. The flux received here at Earth from a star of luminosity *L* at a distance *r* is given by an inverse square law:

$$f(r) = \frac{L}{4\pi r^2}$$

Now consider a thin spherical shell of stars, with radius *r* and thickness *dr*, centered on the Earth (Figure1.31). The intensity of radiation from the shell of stars (that is, the power per unit area per steradian of the sky) will be:

$$\boldsymbol{dJ = \frac{L}{4\pi r^2} \, . \, n \, . \, r^2 dr = \frac{nL}{4\pi} dr}$$

❖ On large scales, the universe is isotropic and homogeneous

What does it mean to state that the universe is isotropic and homogeneous? Saying that the universe is *isotropic* means that there are no preferred directions in the universe; it looks the same no matter which way you point your telescope. Saying that the universe is *homogeneous* means that there are no preferred locations in the universe; it looks the same no matter where you set up your telescope. Note the very important qualifier: the universe is isotropic and homogeneous *on large scales*. In this context, "large scales" means that the universe is only isotropic and homogeneous on scales of roughly 100 Mpc or more.

The isotropy of the universe is not immediately obvious. In fact, on small scales, the universe is blatantly anisotropic. Consider, for example, a sphere 3 meters in diameter, centred on your navel (Figure1.32). Within this sphere, there is a preferred direction; it is the direction commonly referred to as "down". It is easy to determine the vector pointing down. Just let go of a small dense object. The object doesn't hover in midair, and it doesn't move in a random direction; it falls down, toward the center of the Earth.

On significantly larger scales, the universe is still anisotropic. Consider, for example, a sphere 3 AU in diameter, centred on your navel. Within this sphere, there is a preferred direction; it is the direction pointing toward the Sun, which is by far the most massive and most luminous object within the sphere. It is easy to determine the vector pointing toward the Sun. Just step outside on a sunny day, and point to that really bright disk of light up in the sky.

In general, then, saying that something is homogeneous is quite different from saying it is isotropic. However, modern cosmologists have adopted the *cosmological principle*, which states "There is nothing special about our location in the universe." The cosmological principle holds true only on large scales (of 100 Mpc or more). On smaller scales, your navel obviously is in a special location. Most spheres 3 meters across don't contain a sentient being; most sphere 3 AU across don't contain a star; most spheres

3 Mpc across don't contain a pair of bright galaxies. However, most spheres over 100 Mpc across do contain roughly the same pattern of superclusters and voids, statistically speaking. The universe, on scale of 100 Mpc or more, appears to be isotropic around us. Isotropy around any point in the universe, such as your navel, combined with the cosmological principle, implies isotropy around every point in the universe; and isotropy around every point in the universe *does* imply homogeneity.

The cosmological principle has the alternate name of the "Copernican principle" as a tribute to Copernicus, who pointed out that the Earth is not the center of the universe. Later cosmologists also pointed out that the Sun is not the center, that our Galaxy is not the center, and that the Local Group is not the center. In fact, there is no center to the universe.

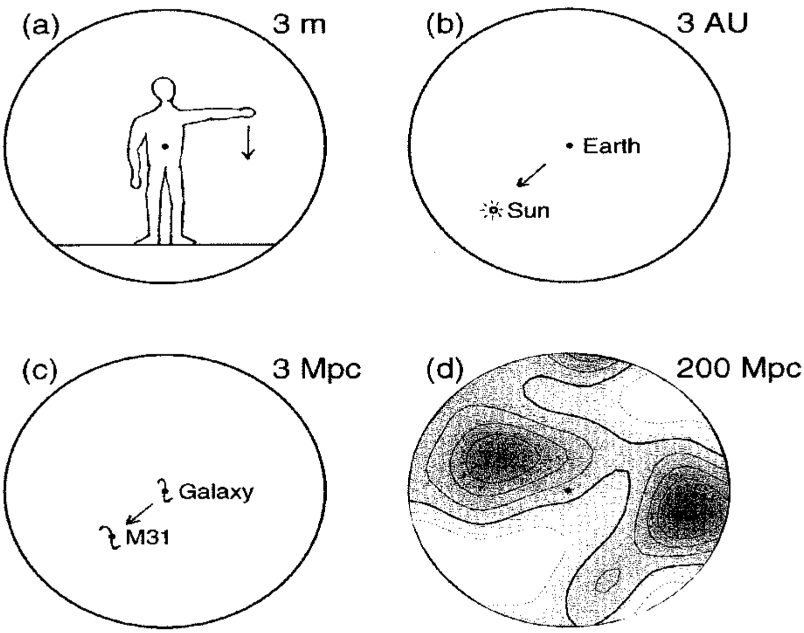

Figure1.32: (a) A sphere 3 meters in diameter, centered on your navel. (b) A sphere 3 AU in diameter, centered on your navel. (c) A sphere 3 Mpc in diameter, centered on your navel. (d) A sphere 200 Mpc in diameter, centered on your navel. Shown is the number density of galaxies smoothed with a Gaussian of width 17 Mpc. The heavy contour is drawn at the mean density; darker regions represent higher density, lighter regions represent lower density (from Dekel et al. 1999, ApJ, 522, 1)

3.2 Evolution of Cosmological theories

Humans have been examining and wondering about the sky for many millennia. As scientific discoveries have been made, ideas about the origin of the universe have changed and are still changing.

A. Ancient Cosmologies

As far back as 1100 BC, Mesopotamian astronomers drew constellations, or formations of stars perceived to form shapes. Some of today's constellation names date back to that time. Mesopotamian and Babylonian cultures mapped the motion of the planets across the sky by observing how they moved against the background of stars.

Until the 16th century, most people (including early astronomers) considered Earth to be at the centre of the universe. Greek philosopher Aristotle proposed a cosmology in about 350 BC that held for thousands of years. Aristotle theorized that the Sun, the Moon, and the planets all revolved around Earth on a set of celestial spheres. These celestial spheres were made of the quintessence—a perfect, unchanging, transparent element. According to Aristotle, the outermost sphere was made of the stars, which appear to be fixed in position. Early astronomers called the stars "fixed stars" to differentiate between stars and planets. The spheres inside the sphere of the fixed stars held the planets, which astronomers called the "wandering stars." The Sun and Moon occupied the two innermost spheres. Four elements (earth, air, fire, and water) are less pure than the quintessence made up everything below the innermost sphere of the Moon. In about 250 BC, Greek astronomer Aristarchus of Sámos became the first known person to assert that Earth moved around the Sun, but Aristotle's model of the universe prevailed for almost 1,800 years after that assertion.

Early astronomers called the planets wandering stars because they move against the background of the stars. Astronomers noted that the planets sometimes moved ahead with respect to the stars but sometimes reversed themselves, making retrograde loops. In about AD 140, Greek scientist Ptolemy explained the retrograde motion as the result of a set of small circles, called epicycles, on which the planets moved. Ptolemy hypothesized that the epicycles moved on larger circles called deferents and that the combination of these motions caused the dominant forward motion and the occasional retrograde loops.

B. **The Sun-CenteredUniverse**

The ideas of Ptolemy were accepted in an age when standards of scientific accuracy and proof had not yet been developed. Even when Polish astronomer Nicolaus Copernicus developed his model of a Sun-centered universe, published in 1543, he based his ideas on philosophy instead of new observations. Copernicus's theory was simpler and therefore more sound scientifically than the idea of an Earth-centered universe. A Sun-centered universe neatly explained why Mars appears to move backward across the sky: Because Earth is closer to the Sun, Earth moves faster than Mars. When Mars is ahead of or relatively far behind Earth, Mars appears to move across Earth's night sky in the usual west-to-east direction. As Earth overtakes Mars, Mars's motion seems to stop, then begin an east-to-west motion that stops and reverses when Earth moves far enough away again. Copernicus's model also explained the daily and yearly motion of the Sun and stars in Earth's sky. Scientists were slow to accept Copernicus's model of the universe, but followers grew in number throughout the 16th century. By the mid-17th century, most scientists in western Europe accepted the Copernican universe.

C. Newton and Beyond

Later in the 17th century, British astronomer Edmond Halley presented British physicist Isaac Newton with a query about the shape of planetary orbits. Newton responded with his three laws of motion (*see* Mechanics: Newton's Three Laws of Motion). Newton also developed the idea of universal gravitation, realizing that the same force that makes an apple fall to Earth also keeps the Moon constantly falling toward Earth, although in the Moon's case Earth continually moves out of the way, resulting in the Moon orbiting the planet. Newton's calculations were eventually expanded into his greatest book, *Philosophiae Naturalis Principia Mathematica*, which was published in 1687. In the *Principia*, Newton derived a wide range of theoretical results about planetary orbits and advanced the law of universal gravity. Newton's laws were the foundation of cosmological thought until the 20th century.

Newton's laws, however, left some questions unanswered. Beginning in the 17th century, scientists wondered why the sky was dark at night if space is indeed infinite (an idea proposed in ancient Greece and still accepted by most cosmologists today) and stars are distributed throughout that infinite space. An infinite amount of starlight should make the sky very bright at night. This cosmological question came to be called Olbers's paradox after the German astronomer Heinrich Olbers, who wrote about the paradox in the 1820s. The paradox was not solved until the 20th century.

In the 19th century, counts of the numbers of stars appearing in different directions in the sky left astronomers with the incorrect idea that Earth and the Sun were approximately in the center of the universe. This conclusion did not take into account the modern idea that dust in our Milky Way Galaxy prevented astronomers from seeing very far in any direction.

4.0 SELF ASSESSMENT EXERCISE

Briefly discuss the evolution of cosmological theories.

5.0 CONCLUSION

In this unit we have learnt the Fundamental observations of modern cosmology and the evolution of cosmological theories.

6.0 SUMMARY

In this unit we have learnt that:

- Cosmology is the study of the universe, or cosmos, regarded as a whole.
- One distance unit used by astronomers is the astronomical unit (AU),equal to the mean distance between the Earth and Sun.
- In metric units, 1 AU = 1.5 $x10^{11}$ m.

- TheSun'smassis1M_0=2.0×10^{30}kg.

The intensity of radiation from the shell of stars (that is, the power per unit area persteradian of the sky) is given by

$$dJ = \frac{L}{4\pi r^2} .n .r^2 dr = \frac{nL}{4\pi} dr$$

- The universe is *isotropic which* means that there are no preferred directions in the universe; it looks the same no matter which way you point your telescope.

7.0 TUTOR MARKED ASSIGNMENT

i. What do you understand by Cosmology?

ii. Discuss the various stages of the Evolution of the cosmological theories.

iii. What is the meaning of isotropic universe?

8.0 REFERENCES/FURTHER READING

Peebles, P. J. E. 1993, Principles of Physical Cosmology (Princeton: Princeton University Press).

UNIT4 MODERN COSMOLOGY

CONTENT

1.0 INTRODUCTION

Modern cosmologists base their theories on astronomical observations, physical concepts such as quantum mechanics, and an element of imagination and philosophy.

2.0 OBJECTIVES

At the end of this unit the reader should be able to:

- Explain the Big-Bang Theory.
- Explain the Steady-State.
- Understand the Future of the Universe.

3.0 MAIN CONTENT

3.1 Modern Cosmology

Cosmologists have moved beyond trying to find Earth's place in the universe to explaining the origins, nature, and fate of the universe.The current "standard model" of the origin of the universe, called the big bang theory, proposes that a major event, not unlike a huge explosion, set free all the matter and energy in the universe and started its expansion. Theories of the evolution and fate of the universe go on to describe a universe that has been expanding and cooling since the big bang. Early versions of the theory held that the universe would keep expanding forever or eventually collapse back to its initial state, an extremely dense object that contains all of the matter in the universe. When the big bang theory was developed in the mid-20th century, some cosmologists found the idea of a sudden beginning of the universe philosophically unacceptable. They proposed the steady-state theory, which said that the universe has always looked more-or-less the same as it does now and that it does not change over time. The steady-state theory could not explain the background radiation, though, and essentially all cosmologists have abandoned it.

A. The Big Bang Theory

The big bang theory describes a hot explosion of energy and matter at the time the universe came into existence. This theory explains why the universe is expanding. Recent versions of the theory also explain why the universe seems so uniform in all directions and at all places.

The work of Edwin Hubble, which showed that the universe is expanding, led cosmologists to begin tracking the history of the universe. The dominant idea is that the universe would have been hotter and denser billions of years ago. In the 1940s Russian American physicist George Gamow and his students, American physicists Ralph Alpher and Robert Herman, developed the idea of a hot explosion of matter and energy at the time of the origin of the universe. (This theory of an explosion at the beginning of the universe was given the originally derisive name “big bang” by British astronomer Fred Hoyle in 1950.) Current calculations place the age of the universe at about 13.7 billion years. Gamow and his students realized that some of the chemical elements in the universe today were forged in the hot early stage of the universe’s existence. They also hypothesized that some radiation that remains from the big bang explosion may still be circulating in the universe, though this idea was forgotten for some time.

Current methods of particle physics allow the universe to be traced back to a tiny fraction of a second (1×10^{-43} seconds) after the big bang explosion initiated the expansion of the universe. To understand the behavior of the universe before that point cosmologists would need a theory that merges quantum mechanics and general relativity. Scientists do not actually study the big bang itself, but infer its existence from the universe's expansion.

In the 1950s American astronomer William Fowler and British astronomers Fred Hoyle, Geoffrey Burbidge, and Margaret Burbidge worked out a series of calculations that showed that the lightest of the chemical elements (those of lowest atomic weight) were formed in the early universe shortly after the big bang. These light elements include ordinary hydrogen, hydrogen's isotope deuterium, and helium. Heavier elements, according to those calculations, were formed later. Scientists now know that the elements heavier than helium and lighter than iron were formed in nuclear processes in stars, and the heaviest elements (those heavier than iron) were formed in supernova explosions.

B. Steady-state Theory

In the 1940s British scientists Hermann Bondi, Thomas Gold, and Fred Hoyle were philosophically opposed to the requirements that the big bang theory put forth for the extreme conditions in the early universe.

The big bang theory was framed in terms of what they called the cosmological principle—that the universe is homogeneous (the same in all locations) and isotropic (looks the same in all directions) on a large scale.

Bondi, Gold, and Hoyle suggested an additional postulate, which they called the perfect cosmological principle. This principle stated that the universe is not only homogeneous and isotropic but also looks the same at all times. Since the universe is expanding, though, one might think that the density of the universe would decrease. Such a decrease would be a change that would not fit with the perfect cosmological principle. Bondi, Gold, and Hoyle thus suggested that matter could be continuously created out of nothing to maintain the density over time.

The rate at which matter would have to be created was much too low to be observationally testable, however. They called this theory the steady-state theory.

3.2 The Future of the Universe

A fundamental issue addressed in cosmology is the future of the universe, whether the universe will expand forever or eventually collapse. The first case (eternal expansion) is known as an open universe, and the second case (eventual collapse) is known as a closed universe.

A closed universe would require sufficiently high density to cause gravity to eventually stop the universe’s expansion and begin its contraction. Such a collapse would require a deviation from Hubble's law, so observational cosmologists try to observe the distances between very distant galaxies and Earth using methods other than measurement of redshifts. The scientists can then compare these distance measurements with the galaxies’ redshifts to see if Hubble’s law holds or not. In the late 1990s astronomers compared the redshifts of supernovas in distant galaxies.

Surprisingly, distant supernovas were slightly fainter than had been expected. This result was tentatively interpreted as an acceleration of the expansion of the universe. Astronomers were so surprised by the suggestion that the universe might be accelerating its expansion that they attempted to find other explanations for the relative dimness of distant supernovas, such as absorption by dust. By a few years into the 21st century, however, these other conceivable explanations had been ruled out, and the accelerating universe concept became widely accepted. The search continues to discover more and more distant supernovas.

4.0 SELF ASSESSMENT EXERCISE

Discuss how modern cosmologists based their theories on astronomical observations.

5.0 CONCLUSION

This unit focussed on modern cosmology. We learnt that modern theories of the evolution and fate of the universe go on to describe a universe that has been expanding and cooling since the big bang.

6.0 SUMMARY

We learnt that:

- Modern cosmologists base their theories on astronomical observations, physical concepts such as quantum mechanics, and an element of imagination and philosophy.
- The current "standard model" of the origin of the universe, called the big bang theory, proposes that a major event, not unlike a huge explosion, set free all the matter and energy in the universe and started its expansion.
- The steady-state theory says that the universe has always looked more-or-less the same as it does now and that it does not change over time.

7.0 TUTOR MARKED ASSIGNMENT

i. What do you understand by the Big-Bang Theory?

ii. Differentiate between Ancient and Modern Cosmologies.

iii. Derive the equation for the Intensity of Radiation from the shell of stars.

8.0 REFERENCES/FURTHER READING

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UNIT 5 SPACE LAW

CONTENT

1.0 INTRODUCTION

International law arises from several sources, chief among them being treaties and custom. Treaties seem an obvious example to the casual observer, and can be enacted bilaterally between two nations, or multilaterally between several countries often with the assistance of the United Nations (UN).They are signed, formal, legal documents. However, custom was the first player, and still an important one, in creating international law. Custom is defined as "general principles of international law not embodied in any treaty but observed, and considered binding, by civilized nations".

2.0 OBJECTIVES

At the end of this unit, the reader should be able to:

- Explain the following Space Treaties:

a. Rescue Agreement

b. Moon Agreement

c. Registration Convention

d. Liability Convention

e. The Limited Test Ban Treaty

f. Outer Space Treaty (OST)

3.1 International Law

International law arises from several sources, chief among them being treaties and custom. Treaties seem an obvious example to the casual observer, and can be enacted bilaterally between two nations, or multilaterally between several countries often with the assistance of the United Nations (UN). They are signed, formal, legal documents. However, custom was the first player, and still an important one, in creating international law. Custom is defined as "general principles of international law not embodied in any treaty but observed and considered binding, by civilized nations".

In addition, commentaries from respected law critics are given due weight in defining international law, as well as resolutions adopted by the UN General Assembly, as they are seen as expressing an international consensus. And not to be neglected is the role of international politics, which at times contributes a large share to international law.

From the above, international law seems a vague and nebulous topic at best, and certainly appears to lack apparent enforcement mechanisms. Unlike violating the civil laws of a nation, there are relatively few expressly defined punishments for violating international law. Economic sanctions and embargoes are largely of symbolic importance, and certainly arresting the "offender" - usually an established nation well equipped with armies and munitions - is impossibility.

Thus, nations are faced with unclear guidelines and unenforceable punishments that govern their interactions. But yet, more times than not, nations abide by the rules of international law. There are several reasons for this as well as reasons for breaking them from time to time:

(a) A system of international law is in the general interest of all nations. It permits business to transact, travel to take place, and cooperation to ensue in health care areas.

(b) Cooperation among nations is imperfect because humans are involved. Humans tend to forget what was agreed upon from time to time, but the formality of a treaty helps to solidify what was agreed upon and serve as a base for negotiating good- and bad-faith disputes that may arise in the future.

(c) Nations guard their own interests, and will violate international law on occasion. Usually this is done very selectively, or else the offending nation faces isolation from the rest of the world for "crying wolf" too many times.

Where Does Space Begin?

One of the first problems early formulators of space law faced was the definition of where space began. How far up from the earth's surface did an object have to be located to be considered "in space" and thus subject to the laws for that arena?

They considered first the von Karman line, an altitude approximately 53-62 miles above the earth's surface where aerodynamic lift is largely nonexistent. This would be the general boundary of airplane flight and thus air law and it seemed a logical point at which to start the domain of space law. They also considered that below an altitude of 69 miles, sustained orbit is practically impossible. Yet, there are violations of these generalizations. The X-15, classified as an airplane, flew at altitudes higher than 62 miles, and satellites have orbited (at certain points in the orbit) lower than 69 miles. The definition which has evolved is as follows: any object that is in orbit about a planet is said to be in space.

This definition falls under "custom", and has never been explicitly delineated in any treaty or other official document. Since there is no tangible black-letter definition, there is the possibility that the current custom of defining "in space" may change in the future to suit the needs of subsequent generations.

Consider the predicament of an aerospace plane, like President Reagan's proposed Orient Express. It would be both an airplane and a spacecraft. So would its passengers be considered "astronauts", and treated like "envoys of mankind" as astronauts are considered under the Rescue Agreement? (see below for information on the rescue agreement) highly unlikely. This is just an example of some of the challenges that might lie ahead in defining, or choosing not to define, clear boundaries for where space begins.

3.2 The Space Treaties

- **The Limited Test Ban Treaty**

Perhaps the first treaty to place guidance on the international norms of behaviour in space was the Limited Test Ban Treaty of 1963. The treaty prohibits the explosion of nuclear devices in the oceans, the atmosphere, and outer space. The US, UK, and the Soviet Union signed this treaty. Other nuclear powers, such as France and China, did not sign the treaty.

Though on the surface this treaty may seem to be aimed at slowing down the nuclear arms race, it actually didn't accomplish that at all, as nuclear tests continued extensively underground by the US and the USSR. From a space point of view though, it was extremely critical to ensuring the success of future satellite missions. Nuclear explosions in space propagate radiation and electromagnetic pulses, which can effectively kill all satellites within a distance of the explosion. Previous explosions at high altitudes caused extensive damage to satellites, and electronics on the ground, and created an artificial radiation belt that apparently persisted for years.

- **Outer Space Treaty (OST)**

This is the Treaty on the Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and other Celestial Bodies, entered into force on October 10, 1967. The Outer Space Treaty has been ratified by 95 States and signed by 27 others.

The OST grew gradually out of a series of conferences on outer space law and several UN General Assembly declarations stating general principles for international activity in outer space. An ad hoc UN Committee on the Peaceful Uses of Outer Space (COPUOS) was established in 1959, and became a permanent UN committee shortly thereafter. In a COPOUS report of 1959, the committee took the position that some form of international administration over celestial bodies might be adopted.

Eisenhower addressed the UN General Assembly in 1960, proposing:
1. We agree the celestial bodies are not subject to national appropriation by any claims of sovereignty.
2. We agree that the nations of the world shall not engage in warlike activities on these bodies.
3. We agree, subject to verification, that no nation will put into orbit or station in outer space weapons of mass destruction. All launchings of spacecraft shall be verified by the UN.

In 1966 President Johnson suggested a treaty be developed containing the following elements:

1. The moon and other celestial bodies should be free for exploration and use by all countries. No country should be permitted to advance a claim of sovereignty.
2. There should be freedom of scientific investigation, and all countries should cooperate in scientific activities relating to celestial bodies.
3. Studies should be made to avoid harmful contamination.

4. Astronauts of one country should give necessary help to astronauts of another country.
5. No country should be permitted to station weapons of mass destruction on a celestial body. Weapons tests and military manoeuvres should be forbidden.

After nearly a decade of debate in the UN, the OST was ratified and entered into force in 1967. The main points in the OST can be summed up as follows:
(a) Terrestrial sovereignty may not be extended to space or celestial bodies.

(b) No weapons of mass destruction shall be placed in orbit or on celestial bodies, or stationed in outer space in any manner; celestial bodies shall be used exclusively for peaceful purposes.

(c) Assistance and return of astronauts and space vehicles; notification of dangerous phenomena in outer space or on celestial bodies.

(d) Parties shall bear international responsibility for national activities in outer space.

(e) Parties to the treaty that launch or procure the launching of objects into outer space shall be liable for damages.

(f) Jurisdiction and control over personnel and objects are not affected by their presence in outer space or on celestial bodies.

(g) Parties to the treaty shall avoid harmful contamination of outer space, celestial bodies, and the environment of earth, and shall consult with other parties regarding potentially harmful experiments.

In order to understand why the treaty was considered such a success, it is important to understand a bit of the world climate at the time of its formulation. In 1966, the cold war was raging between the U.S. and the former Soviet Union and tensions were high. The new arena of space left many people on both sides speculating about its military applications, with particular emphasis on nuclear weapons deployment to earth targets from outer space. The Soviets had been consistently launching men and satellites into space for several years, while the U.S. was doing much the same with its Mercury and Gemini manned programs. About this time as well, both countries were well into planning for manned missions to the moon. It is also important to point out that the U.S. and the former Soviet Union were the superpowers at that time, in addition to being the only countries with space capabilities.

- **Liability Convention**

This is the Convention on International liability for Damage caused by Space Objects, entered into force on September 1, 1972. It has been ratified by 80 States and signed by 26 others.

This is a major space law agreement that fleshes out the liability provisions laid out in the OST. It applies to both military and civilian space activities, and provides for:
• Absolute liability by launching states for damage caused by their space objects to objects on the earth or to aircraft in flight.
• Liability based on fault where the damage is to space objects of another launching state elsewhere that on the surface of the earth (ie. in space).

There has been one significant real world application of the liability convention. In 1978, a Cosmos 954 satellite powered by nuclear reactor and belonging to the USSR crash landed in Canada. Radioactive debris was scattered over Saskatchewan, Alberta, and the Northwest Territories. Both the US and Russia offered to help Canada with the cleanup. Canada accepted the US offer and denied the Soviet offer. But after the cleanup, the Canadian government sent the USSR a bill for Canadian $6M, as they thought they were entitled under the liability convention. The Soviet government only paid C$3M, believing that they offered to help in kind with the cleanup and should therefore not be obligated to pay the full amount. The implementation of the liability convention, as we see in this case, involves politics as much as it involves international law. And likely it will continue to be this way.

- Rescue Agreement

  This is the Agreement on the Rescue of Astronauts, and Return of Astronauts and the Return of Objects launched into Outer Space, entered into force on December 3, 1968. It has been ratified by 85 States and signed by 26 others.

This treaty suggests that astronauts are the envoys of mankind, and encourages nations to treat them as such. It provides for:

• The return of astronauts if they crash land on foreign territory
• The rescue of an astronaut if he/she is in trouble
• The return of space objects to their rightful owners is they emergency- or crash-land in foreign territory.

- Registration Convention

Convention on Registration of Objects launched into Outer Space, entered into force on September 15, 1976. It has been ratified by 40 States and signed by 4 others.

This treaty requires all launching states to keep a registry for objects launched from their territories or under their supervision, and report this registry to the UN from time to time.

- Moon Agreement

This is the Agreement Governing the Activities of States on the Moon and other Celestial Bodies, entered into force on July 12, 1984. It has been ratified by 9 States and signed by 5 others.

The rules against extension of sovereignty to outer space and celestial bodies resolved a good deal of confusion regarding such matters. Certainly, prior to the OST entering into force, there had been considerable uncertainty regarding the ability of nations to claim sovereignty in space based on arriving at a particular place first, especially after the former Soviet Union planted a flag on the moon using an unmanned probe. However, there still remained some questions regarding outer space resource utilization and property rights. The Moon Agreement was an attempt to clarify the remaining problems.

The Moon Treaty introduced the "common heritage of mankind" principle. This essentially said that the moon could not be appropriated or claimed by any individual or states parties, and Paragraphs 5 and 7d indicate that there will be an equitable distribution to all countries of the benefits of those lunar resources controlled by the future international regime. "Thus, even though national appropriation of the moon is prohibited, and even though the surface and the subsurface of the moon cannot become property of the various listed entities, numerous activities which are usually associated with appropriation and property rights are explicitly allowed." The United States believed that this limitation on appropriation would be detrimental to its economy because it was contrary to the economic interests of the U.S. and of other countries with a free enterprise system. Senators at the time, being prodded by aerospace companies with interests in future resource mining on the moon, voiced their concerns to the Secretary of State, Cyrus Vance. Vance took an interpretation of the treaty that was typical of the US view at that time: that resource appropriation and ownership is actually permitted by the Moon Treaty, and that limitations on resource exploitation only apply to natural resources when they are in their natural place.

4.0 SELF ASSESSMENT EXERCISE

What do you understand by the term Space and where does it begin?

5.0 CONCLUSION

In this unit we have discussed the various international space laws and treaties. We also looked at Space and where it begins.

6.0 SUMMARY

In this unit we have learnt that:

- International space law arises from treaties and custom.
- Custom is defined as "general principles of international law not embodied in any treaty but observed and considered binding, by civilized nations".
- A system of international law is in the general interest of all nations. It permits business to transact, travel to take place, and cooperation to ensue in health care areas.

7.0 TUTOR MARKED ASSIGNMENT

Discuss the following Space Treaties:

a. Rescue Agreement

b. Moon Agreement

c. Registration Convention

d. Liability Convention

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