1. Details of Module and its structure

Subject Name	Physics
Course Name	Physics 01 (Physics Part-1, Class XI)
Module Name/Title	Unit 6, Module 4, Satellite and their launching Chapter 8, Gravitation
Module Id	Keph_10804_eContent
Pre-requisites	Gravitational force, Gravitational potential energy, kinetic energy, mechanical energy, centripetal force.
Objectives	After going through this lesson, the learners will be able to: • **Understand the Concept** of an artificial satellite • **Define** satellite Parameters- a satellite's orbit Orbital velocity, time period and height above the earth surface • **Explain t**he conditions for the launching of satellite • **Know** about geostationary and polar satellites • **Be informed** of ISRO's work in the field of launching satellites • **Understand** the meaning of escape velocity
Keywords	Satellites, orbital velocity, time period, Binding energy geostationary satellite, polar satellite

2. Development Team

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1. UNIT SYLLABUS

Unit VI: Gravitation

Chapter 8: Gravitation

Kepler’s laws of planetary motion, Universal law of gravitation.

Acceleration due to gravity and its variation with altitude and depth.

Gravitational potential energy and gravitational potential; escape velocity; orbital velocity of a satellite; Geo-stationary satellites.

2. MODULE-WISE DISTRIBUTION OF UNIT SYLLABUS 5 Modules

The above unit is divided into five modules for better understanding.

Module 1	• Gravitation • Laws of gravitation • Early studies • Kepler's laws
Module 2	• Acceleration due to gravity • Variation of g with altitude • Variation of g due to depth • Other factors that change g
Module 3	• Gravitational field • Gravitational energy • Gravitational potential energy • Need to describe these values
Module 4	• Satellites • India's satellite programme and target applications • Geo stationary satellites and Polar satellites • Escape velocity • India's space program
Module 5	• Numerical problems based on Gravitation

MODULE 4

3. WORDS YOU MUST KNOW

- **Gravitational force:** Force of attraction between two objects of some mass.
- **Celestial bodies**: Stars, Planets, comets, asteroids etc.
- **Ellipse:**A regular oval shaped curve which is the locus of a point moving in a plane so that the sum of its distances from two other points (the foci) is constant,
- **Eccentricity of an ellipse**: It is the measure of deviation of the ellipse from circularity.
- **Areal velocity**: It is the rate at which area is swept out by a particle as it moves along a curve. In Kepler's law of areas, the particle is the planet and curve is the orbit in which it moves around the sun
- **Kepler's laws of Planetary Motion :**

Law of orbits:

All planets move in elliptical orbits with the Sun situated at oneof the foci of the ellipse.

Law of Areas:

The line that joins any planet to the suns weeps equal areas inequal intervals of time

Law of periods:

The Square of the time period of revolution of a planet is proportional to the cube of the semi-major axis of the ellipse traced out by the planet.

- **Newton's Universal Law of gravitation**: It states that the gravitational force between two point masses is directly proportional to the product of their masses and inversely proportional to the square of the distance between them.

- **Principle of superposition**: If we have a collection of point masses, the force on any one of them is the vector sum of the gravitational forces exerted by the other point masses

- **Universal gravitational constant**: Denoted by the letter G, it is an empirical physical constant involved in the calculation of gravitational effects in Newton's law of universal gravitation. It is a *universal constant* with the value 6.673×10^{-11}N m^2 kg^{-2}.

- **Acceleration due to gravity**: Acceleration experienced by an object due to the force of gravitational attraction of the earth.
- **Variation of acceleration due to gravity:** The acceleration due to gravity decreases with both altitude and depth.
- **Work Energy theorem**: The change in kinetic energy of the object is equal to the net work done by all the forces acting on the object.
- **Conservative force**: The work done by this force is independent of the path taken and in a round trip; the work done by it is zero.
- **Non conservative force**: The work done by this force is dependent of the path taken and in a round trip; the work done by it is not zero.
- **Mechanical energy**: It is the sum of kinetic energy and potential energy.
- **Gravitational potential energy**: Potential energy by virtue of the gravitational force.
- **Kinetic energy**: Energy possessed by an object by virtue of its motion.
- **Projectile**: An object moving only under the influence of gravity.
- **Centripetal force**: Radial force towards the centre of the circular path in which the object is moving.

4. INTRODUCTION

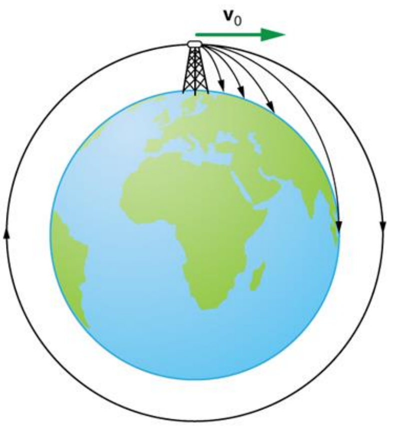
Objects which orbit around the planets are called satellites. Satellites are always smaller in size and mass as compared to the planet. The moons of the planets are their natural satellites. Apart from natural satellites,wehave learned to launch satellites made by us around the planets. These satellites are artificial satellites. We will learn about the artificial satellites in this module. The artificial satellites which are currently orbiting the earth are the reason why we are enjoying the advance technology like internet services, Global Positioning System, live telecast of television shows from one part of the world to the other and many others.

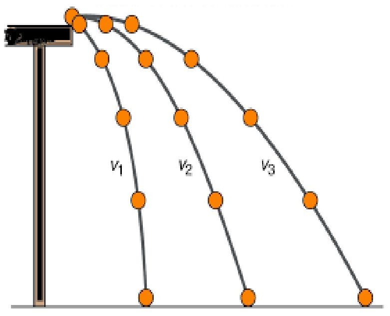
Satellite as a projectile:

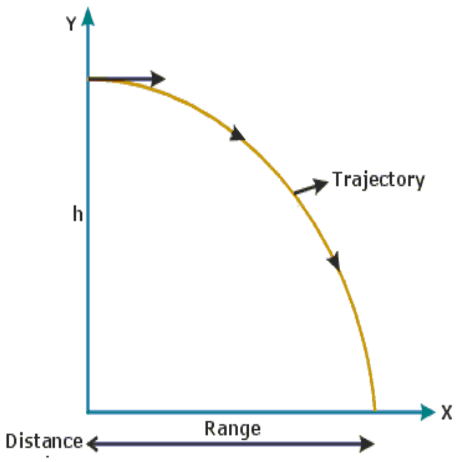
Let us consider this situation:

We take an object to a certain height from the ground and throw it horizontally. When the object is released, it moves under the influence of only gravity in a parabolic path and it will cover some ground (range) before it hits the earth.This object is referred to as a projectile.

If the velocity with which the object is thrown is increased gradually, it will cover more and more ground (range) before it hits the earth. Now since the earth is almost a sphere, at very large velocity of projection, the object might miss the curvature of the earth and continue in its free fall in search of the ground. This object will keep going around the earth in circular orbits and will become the satellite of the earth.







5. PARAMETERS OF A SATELLITE

i) ORBITAL VELOCITY:

The velocity with which a satellite moves around the earth is called the orbital velocity.

If the orbit of the satellite is circular, the centripetal force required for the satellite to be in orbit is provided by the gravitational force.

If M is the mass of the earth and m is the mass of the satellite and r is the orbital radiusand v is the velocity of the satellite then we have:

$$\frac{mv^2}{r} = \frac{\text{GMm}}{r^2}$$

$$v = \sqrt{\frac{GM}{r}} = \sqrt{\frac{gR^2}{r}}$$

Orbital radius of satellite in R (radius of earth)	Orbital velocity of satellite v	Value of orbital velocity
R	$\sqrt{gR}$	7.92km/s
2R	$\sqrt{\frac{gR}{2}}$	5.6 km/s
3R	$\sqrt{\frac{gR}{3}}$	4.57km/s
4R	$\sqrt{\frac{gR}{4}}$	3.96km/s
5R	$\sqrt{\frac{gR}{5}}$	3.54km/s
6R	$\sqrt{\frac{gR}{6}}$	3.23km/s

POINTS TO BE NOTED:

- **Orbital velocity of a satellite orbiting very close to the surface of the earth is maximum and is equal to 7.92 km/s**
- **Orbital velocity of the satellite decreases inversely with the square root of the orbital radius of the satellite. Hence the satellites moving in larger orbits are slower as compared to satellites moving in smaller orbits around the earth.**
- **Orbital velocity of the satellite is independent of the mass of the satellite.**

ii) TIME PERIOD OF SATELLITE

The time taken by the satellite to complete one revolution around the earth is termed as the time period of the satellite.

$$T = \frac{2\pi r}{v}$$

Substituting the value of orbital velocity v, the time period of the satellite is

$$T = \frac{2\pi r^{3/2}}{\sqrt{GM}} = \frac{2\pi r^{3/2}}{\sqrt{gR^2}} = \frac{2\pi r^{3/2}}{R\sqrt{g}}$$

Hence we see that the time period of the satellite around the planet varies in accordance with the Kepler's law of periods. This law was stated by Kepler for the motion of planets around the sun according to which we know that the square of the time period of planets is directly proportional to the cube of its mean distance from the sun.

$$T^2 \propto r^3$$

Orbital radius of satellite in terms of R(radius of earth)	**Time period of the satellite**	**Value of the time period of the satellite.**
R	$2\pi\sqrt{\frac{R}{g}}$	84.4 min
2R	$2^{3/2}2\pi\sqrt{\frac{R}{g}}$	4hrs
3R	$3^{3/2}2\pi\sqrt{\frac{R}{g}}$	7.3hrs
4R	$4^{3/2}2\pi\sqrt{\frac{R}{g}}$	11.25hrs
5R	$5^{3/2}2\pi\sqrt{\frac{R}{g}}$	15.7hrs
6R	$6^{3/2}2\pi\sqrt{\frac{R}{g}}$	21hrs
6.5R	$6.5^{3/2}2\pi\sqrt{\frac{R}{g}}$	24hrs(approx.)

POINTS TO BE NOTED:

1. **Time period of the satellite increases with increase in the orbital radius of the satellite.**
2. **The minimum time period of a satellite is 84. 4 min or nearly 1.4 hours. This is for a satellite moving very close to the earth surface.**
3. **The time period of a satellite which is orbiting at a distance of 6.5 times the radius of the earth is nearly 24 hours.**

iii) ORBITAL RADIUS OF A SATELLITE

The height of a satellite above the surface of the earth determines the orbital radius of the satellite from the centre of the earth.

Once the orbital radius of the satellite is decided, the time period of revolution of the satellite around the earth also gets decided by the Kepler's law of periods. This is turn also decides the orbital velocity of the satellite.

Hence, the height at which a satellite is injected into an orbit around the earth determines the parameters of the satellite.

iv) ENERGY OF A SATELLITE

A satellite orbiting the earth at a orbital radius (r) has a kinetic energy by virtue of its orbital velocity (v) around the earth. This kinetic energy of the satellite is equal to

$$K = \frac{1}{2} mv^2$$

$$= \frac{GMm}{2r}$$

The satellite also possesses a potential energy by virtue of its distance (r) from the centre of the earth (orbital radius)

$$U = -\frac{GMm}{r}$$

Hence the total mechanical energy possessed by a satellite is given by

$$E = K + U = -\frac{GMm}{2r}$$

The negative sign of the total energy of the satellite signifies the fact that the satellite is bound to the earth.

The energy of the satellite is a function of the orbital radius and the mass of the satellite. The greater the orbital radius of the satellite and greater the mass of the satellite, greater will be its energy. Hence,greater energy is required to launch a heavy satellite at a greater height above the surface.

Kinetic energy of the satellite decreases with increase in the orbital radius of the satellite. This is because the orbital velocity decreases with height from the surface of the earth

Kinetic energy K = – Total energy, E

Potential energy of the satellite increases with increase in the orbital radius of the satellite.

Potential energy = 2 (Total energy)

Also the Potential energy = – 2(kinetic energy)

EXAMPLE:

A 400 kg satellite is in a circular orbit of radius 2R$_E$ about the Earth. How much energy is required to transfer it to a circular orbit of radius 4R$_E$? What are the changes in the kinetic and potential energies?

SOLUTION:

Energy of the satellite in orbit of radius 2R$_E$ is

$E_{initial} = -\frac{GMm}{4R}$

Energy of the satellite in orbit of radius 4R$_E$ is

$E_{final} = -\frac{GMm}{8R}$

The change in the total energy is:

$\Delta E = E_{final} - E_{initial}$

$$= \frac{GMm}{8R} = 3.13 \times 10^9 \text{ J}$$

Change in kinetic energy $\Delta K = K_f - K_i = -\Delta E = -3.13 \times 10^9$ J

Change in potential energy is twice the change in the total energy, namely

$\Delta U = 2\Delta E = 6.25 \times 10^9$ J

6. TYPES OF SATELLITES

i) GEOSTATIONARY SATELLITES

Satellites which are orbiting near the surface of the earth move very fast and hence they cannot communicate with a small portion of the earth for a longer period of time. But if we have satellites which can always stay over a particular region, they can be used to monitor and communicate with that region. Such satellites are geostationary or geosynchronous satellites. They are placed in special orbits around the earth called the geosynchronous orbits.

A geosynchronous orbit,is a high earth circular orbit such that the satellites placed in this orbit have a time period of 24 hours. Since the satellite orbits at the same speed that the earth is rotating, the satellite seems to be stationary over a certain place over a single longitude but its orbit may be tilted, or inclined, a few degrees north or south.

The orbit is located 35,786 km above the earth's equator or having an orbital radius of 42160 km.

The geosynchronous orbit is a valuable spot for monitoring weather, communications mainly involving satellite TV and satellite Radio and surveillance. A satellite in this orbit can see one spot of the planet almost all of the time. For Earth observation, this allows the satellite to look at how much a region changes over months or years. The satellite antenna on the ground can receive a signal while always pointing the same way.A single geostationary satellite is on a line of sight with about 40 % of the earth's surface. Three such satellites, each separated by 120 degrees of longitude, can provide coverage of the entire planet, with the exception of small circular regions centred at the north and south geographic poles.

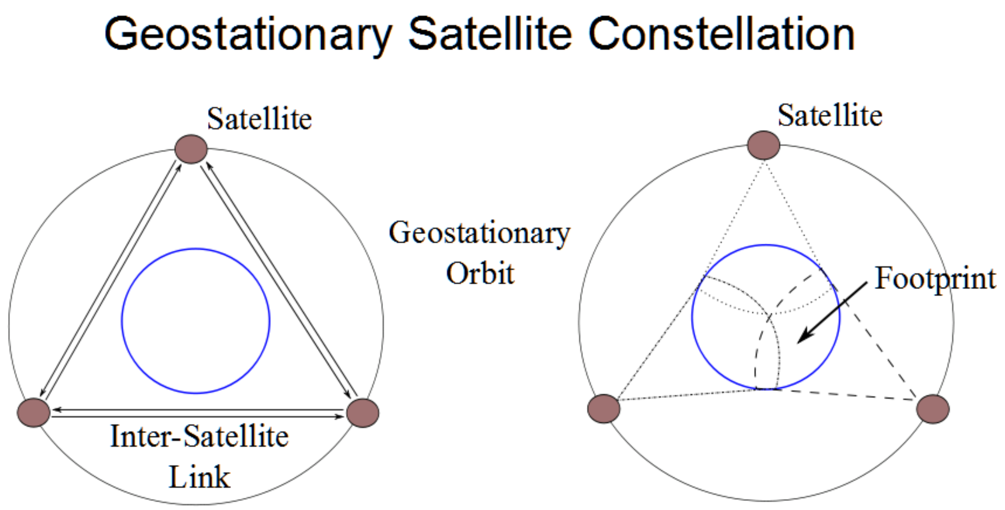
Need of satellites in other orbits:

Although there are a lot of **advantages of geostationary** satellites, there are some drawbacks associated with these satellites.

- The cost of launching Geostationary satellites is quite high as rocket requires a lot of fuel to place the satellite into the high earth's orbit

- There is a lack of coverage of areas near the geographic poles

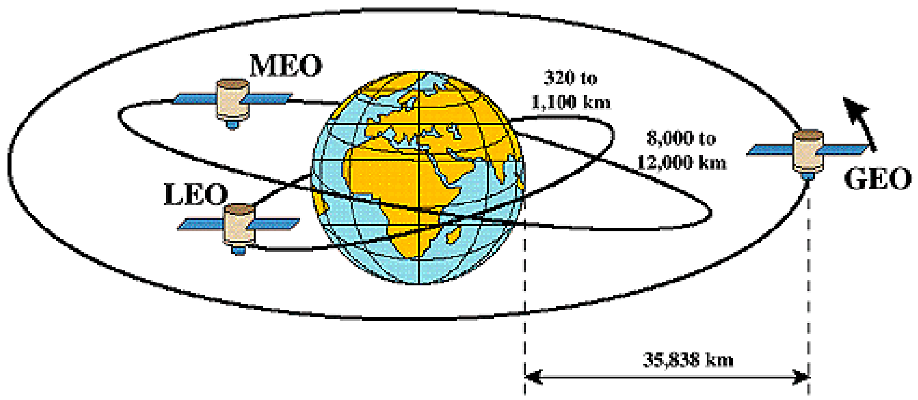
- Any signal sent from Earth to the satellite and back takes at least a quarter of a second to complete the trip, which is not insignificant for latency-sensitive applications. (Latency refers to short period of delay between when audio signal enters and

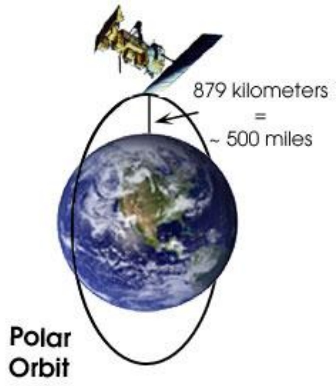


emerges from the system.)

Hence satellites are placed in various orbits which are categorized **according to the orbital radius**

- **Low earth orbit (320 km to 1100 km)**
- **Medium earth orbit (8000 km to 12,000 km)**
- **Geostationary orbit (42000km)**





Among the satellites in the low earth orbit is the International space station orbiting the earth at a height of about 400km from the surface of the earth.

Satellites in the medium earth orbit comprise the satellites of the earth which completes one orbit once in about 12 hours.

ii) POLAR SATELLITES

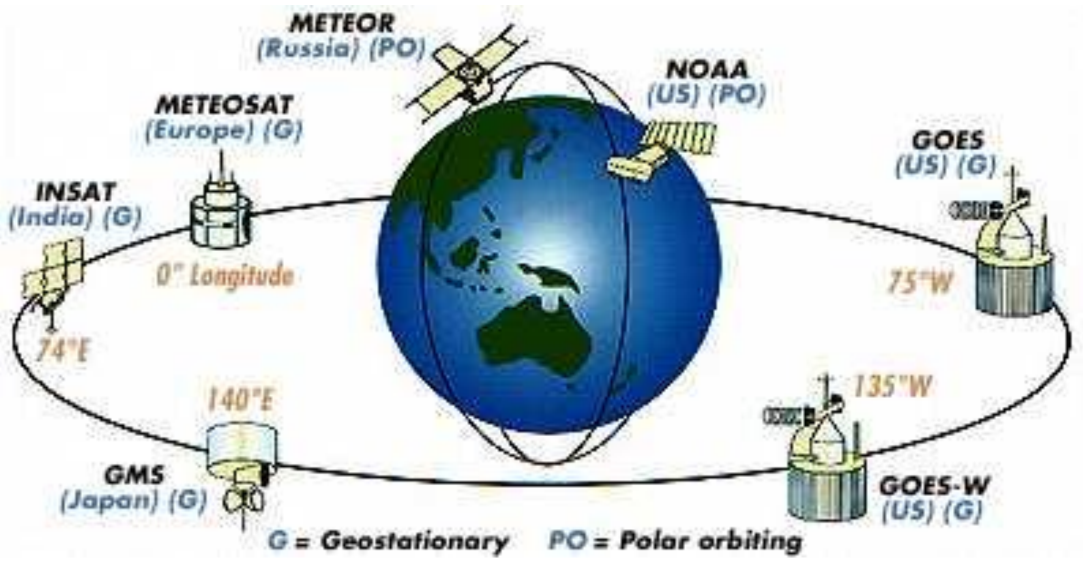
Polar satellites pass over the north and south poles in each revolution.
They have highly inclined orbit close to 90°. As the earth rotates to the east beneath the satellite, each pass monitors an area to the west of the previous pass at intervals of roughly 90 to 100 minutes.

Small strips of the earth are photographed by the camera placed on these satellites. These strips can be pieced together to produce a picture of a larger area. Since these Polar satellites circle at low altitude of about 850km, they provide more detailed information about violent storms and cloud systems. Various environmental and weather satellites such as the NOAA and TIROS series, or the METEOR satellites are included in this category.
Hence the polar satellites are extremely useful for remote sensing, meteorology as well as for environmental studies of the earth.
Figure below shows some satellites which have been placed in the Polar and the Geostationary orbits by various countries.

WEIGHTLESSNESS IN A SATELLITE:

A satellite is an object which orbits around a planet. It is also a projectile which is in a state of free fall. The centripetal force required for its motion is provided by the gravitational force.

Weight of a body is the force with which it is attracted towards the earth. The body experiences this weight due to the reaction from the ground. If there is no reaction or contact force the body will not experience any weight or it will be in a state of weightlessness. The contact force by the surface of the satellite on the things inside it is zero. If the satellite is a space station like the International space station which is orbiting the earth at a height of 400km, the people inside it experience weightlessness and float inside the space station.



7. ESCAPE VELOCITY

If an object is thrown up from the surface of the earth, it covers some height and then it returns back after some time. The kinetic energy of the object goes on decreasing as it ascends and at one point it becomes zero. It is then, that the object starts its journey back to the earth.

If the object is thrown up with a greater speed, it will cover a greater height before it starts returning back to the earth.

Now if we go on increasing the speed further and further, the object will cover greater and greater height before its kinetic energy to be zero. But if the speed is very high, the object will never reach a finite height where its kinetic energy will become zero. This object will reach a very far off distance or infinity. We then say that the object has escaped from the gravitational pull of the planet.

Applying the law of conservation of energy we say that the energy of the object at time of projection from the surface of the earth is equal to the energy of the object at infinity

E(surface) = Kinetic energy + potential energy

$= \frac{1}{2} mv^2 - \frac{GMm}{R}$

E(infinity) = 0

$\frac{1}{2} mv^2 - \frac{GMm}{R} = 0$

$v = \sqrt{\frac{2GM}{R}}$ = escape speed

Astronomical body	Mass (in earth mass)	Radius (in earth radius)	Escape speed (km/s)
Sun	333000	109	620
Mercury	0.055	0.38	4.3
Venus	0.82	0.95	10.4
Earth	1.00	1.00	11.2
Moon	0.0123	0.28	2.4
Mars	0.11	0.53	5.0
Jupiter	318	11	60.2
Saturn	95.2	9.2	36.0
Uranus	14.5	3.7	22.3
Neptune	17.3	3.47	24.9

POINTS TO BE NOTED:

- **The escape speed from a planet depends on the mass and the radius of the planet.**
- **Hence the escape speed of a planet is a characteristic of that planet.**
- **The escape speed from the moon is very low. This is also the reason for the absence of atmosphere on the moon. The thermal velocity of the air molecules was greater than the escape speed of the moon, hence all the air molecules escaped from the surface of the moon.**

If a satellite is orbiting the planet then the total energy of the satellite is given by

E = $-\frac{GMm}{2r}$

If a satellite is provided an energy equal to this energy

i.e. $E = \frac{GMm}{2r}$

The satellite will escape from the gravitational force of the planet. This energy is called the binding energy. The greater the height of the satellite, lesser will be the energy required by the satellite to escape.

Escape velocity of an object at a orbital radius r is given by:

$v = \sqrt{\frac{2GM}{r}}$= √2 x orbital velocity at r

Hence the escape velocity at a given height is √2 times the speed in a circular orbit at the same height.

Example: The escape velocity of a geo stationary satellite is only 4.3 km/s

The escape velocity relative to the surface of a rotating body depends on direction in which the escaping body travels. For example, as the Earth's rotational velocity is 465 m/s at the equator, a rocket launched tangentially from the Earth's equator to the east requires an initial velocity of about 10.735 km/s relative to Earth to escape whereas a rocket launched tangentially from the Earth's equator to the west requires an initial velocity of about 11.665 km/s relative to Earth. The surface velocity decreases with the cosine of the geographic latitude, so space launch facilities are often located as close to the equator as feasible, e.g. the American Cape Canaveral (latitude 28°28' N) and the French Guiana Space Centre (latitude 5°14' N).

Interplanetary mission require a rocket to attain the escape velocity to break free from the gravitational pull of the earth. Achieving the escape velocity is the most challenging task in the space missions. A great thrust is required for it. This thrust can be increased only by increasing the fuel of the rocket but this in turn increases the weight of the rocket. So the use of special engines is required for such rockets carrying payloads which have to go to another planet or the moon.

Saturn V was one such rocket which was sent to the moon.

Mangalyaan mission to Mars by ISRO required the rocket to attain the escape velocity This was attained in various phases when the orbit was raised using the spacecraft's on-board propulsion system and a series of perigee burns. The apogee was raised to 192,874 km on 15 November 2013 in the final orbit raising manoeuvre. The aim was to gradually build up the necessary escape velocity of 11.2 km/sto escape the earth's gravitational pull.

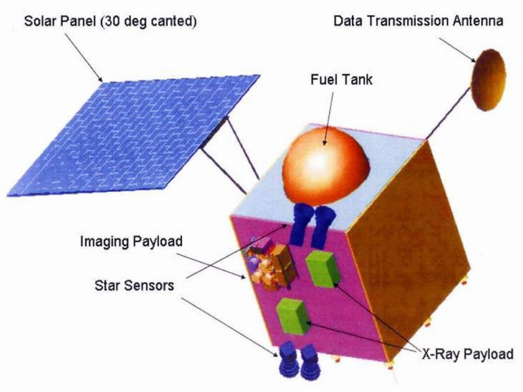
8. INDIA'S SATELLITE PROGRAM

India has come a long way since 19th April, 1975 when Indian Space Research Organisation(ISRO) made its first satellite, Aryabhatta, which was launched by Soviet Union. On 22nd June, 2016, ISRO launched 20 satellites of different nations in its own vehicle, Polar Satellite Launch Vehicle, PSLV-C34 in only 26 minutes from SatishDhawan Space Centre SHAR, Sriharikota. This was the thirty fifth consecutively successful mission of PSLV. The total weight of all the 20 satellites carried on-board PSLV-C34 was 1288 kg. Among the satellites launched was the Indian satellite Cartosat-2C which weighed 727.5kg.

Indian Space Research Organisation was established in **1962** by India's first Prime minister, Jawaharlal Nehru and his close aide and scientist Vikram Sarabhai which has its headquarters in Bengaluru, Karnataka.

Rohini became the first satellite to be launched in orbit by an Indian launch vehicle, SLV-3 in 1980.ISRO subsequently developed two other rockets: Polar Satellite Launch Vehicle(PSLV) and Geosynchronous Satellite Launch Vehicle (GSLV) for placing satellites in Polar and Geostationary orbits respectively.These rockets have launched many satellites which are used for communication and weather monitoring. Satellite navigation systems like GAGAN and IRNSShave been deployed. In January 2014, ISRO made history when it successfully used an indigenous cryogenic engine in a GSLV-D5 launch of the GSAT-14.

Some other breakthrough by ISRO was Chandrayaan-1, the lunar orbitersent on 22 October 2008 and one Mars orbiter, Mars OrbiterMission(MOM) , which successfully entered Mars orbit on 24 September 2014, making India the first nation to succeed on its first attempt, and ISRO the fourth space agency in the world as well as the first space agency in Asia to successfully reach Mars orbit.



ISRO has launched a total of 131 satellites using indigenously developed launch vehicles out of which 74 are foreign. Also, 29 Indian satellites have been launched by foreign launch vehicles.

INSAT series:

INSAT (Indian National Satellite System) is a series of multipurpose geostationary satellites launched by ISRO to satisfy the telecommunications, broadcasting, meteorology and search-and-rescue needs of India.

IRS series:

The IRS (Indian Remote Sensing Satellite system) is the largest constellation of remote sensing satellites maintained by ISRO for civilian use in operation today in the world. All the satellites are placed in polar Sun- synchronous orbit.

GSAT series:

ISRO has also launched a set of experimental geostationary satellites known as the GSAT series.GSAT-8 carried the GAGAN payload which is the GPS based geo-augmented navigation.

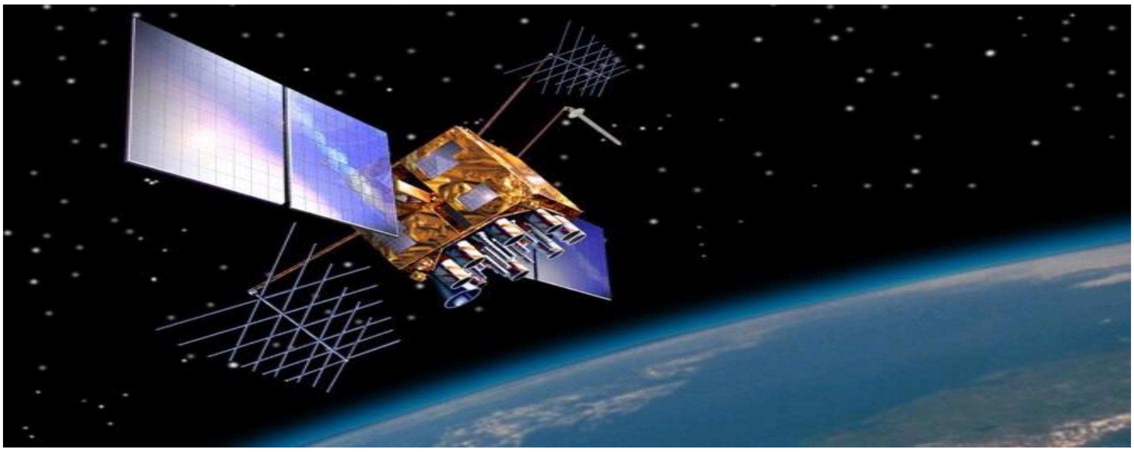
RISAT series:

ISRO currently operates two Radar Imaging Satellites. It carried a C-band Synthetic Aperture Radar (SAR) payload that can provide images with coarse, fine and high spatial resolutions.

Our mission to the Moon:

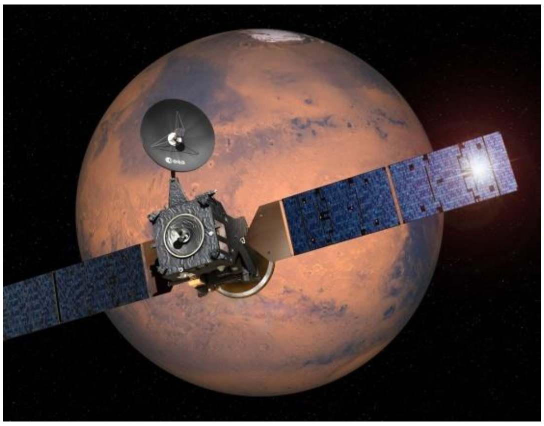
CHANDRAYAAN-1

was India's first unmanned mission to the moon. ISRO launched the spacecraft using a modified version of the PSLV on 22 October 2008 SatishDhawan space centre, Sriharikota. The vehicle was successfully inserted into lunar orbit on 8 November 2008. It carried high-resolution remote sensing equipment for visible, near infrared, and soft and hard X-ray frequencies. During its 312 days operational period, it surveyed the lunar surface to produce a complete map of its chemical characteristics and 3-dimensional topography.



CHANDRAYAN 2

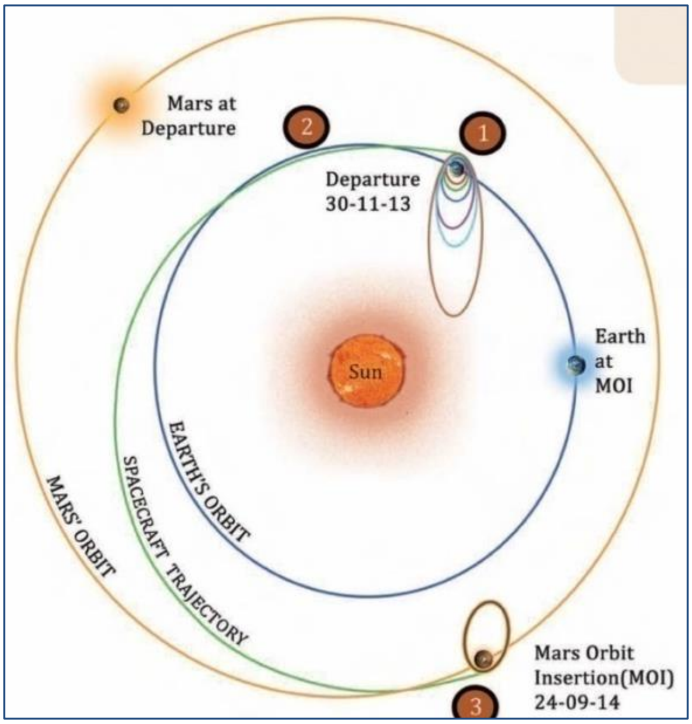
Chandrayaan 2 is an Indian Space Research Organization (ISRO) mission comprising an orbiter and a soft lander carrying a rover, scheduled to launch to the Moon in July 2019. The primary objective of Chandrayaan 2 is to demonstrate the ability to soft-land on the lunar surface and operate a robotic rover on the surface. Scientific goals include studies of lunar topography, mineralogy, elemental abundance, the lunar exosphere, and signatures of hydroxyl and water ice.



https://www.isro.gov.in/sites/default/files/galleries/Chandrayaan-2%20Mission%20Gallery/liftoffimage12.jpg

OUR MARS MISSION (MANGALAYAAN)

The Mars Orbiter mission (MOM), known as *Mangalayaan*, was launched into Earth orbit on 5 November 2013 by the Indian Space Research Organisation (ISRO) and entered Mars orbit on 24 September 2014. India is the first country to enter Mars orbit in first attempt. The mission was completed at a record cost of $74 million.



The spacecraft had a launch mass of 1,337 kg, with 15 kg of five scientific instruments as payload.

9. SUMMARY

- A body which is revolving in an orbit around a comparatively much larger body is called a satellite. Natural satellite of earth is moon while artificial satellite includes the INSAT satellites
- Orbital velocity of a satellite is the minimum speed required to the satellite into a given orbit around earth.
- Time taken by a satellite to complete one revolution around the planet is known as the time period of the satellite
- The total energy of a satellite is the sum of its potential and kinetic energy.
- A satellite in a circular orbit around the Earth in the equatorial plane, having a time period equal to the time period of earth's rotation appears stationary to an observer on the earth. This is a Geo-stationary satellite and is very useful for communication purposes.
- Polar satellites are low altitude satellites which circle the earth in a North- South orbit passing over the north and south poles
- Satellites are in a free fall and hence a body in it experiences weightlessness.
- The minimum speed with which a body should be projected vertically upward from the surface of the earth such that it can escape the earth's gravitational pull is called the escape velocity of the planet.
- Indian Space Research Organisation (ISRO) has attained a prominent place in International space community after developing its satellite and rocket launching technologies. We have been able to go to the moon and mars using our own technologies.