DU 10. THE UNIVERSE AND GRAVITY

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1. COSMOLOGY. THE STUDY OF THE UNIVERSE

There are billions of galaxies in the Universe. The most distant are so far away that their light has taken more than 10 thousand million years to reach us. Indeed, the light started its journey almost right back at the beginning of time itself.

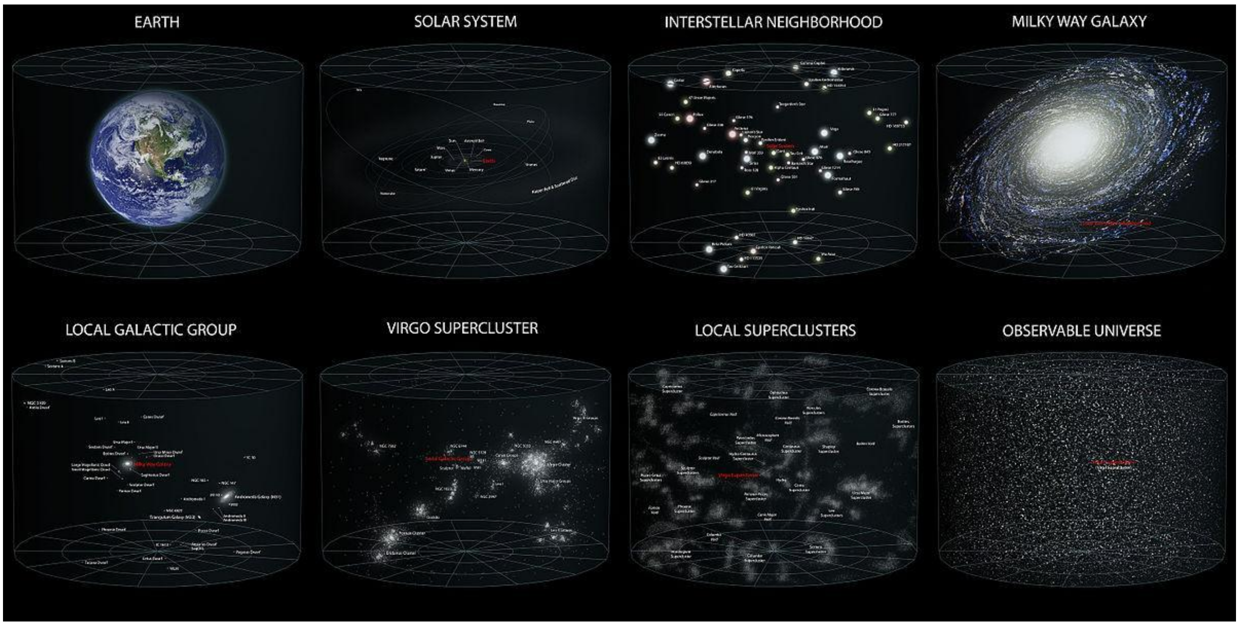


Figure 10.1

The image shows a diagram of the Earth's location in the Universe, in a series of eight maps that show, from left to right, starting with the Earth, moving to the Solar System, then onto the Solar Interstellar Neighbourhood, onto the Milky Way, onto the Local Galactic Group, onto the Virgo Supercluster, then to our local superclusters, and finishing with the observable Universe.

There is an old, simple question that can help us to understand a fundamental property of the Universe. The question is usually called **Olbers' Paradox**, (after German astronomer Heinrich W. Olbers), and it can be stated pretty simply:

Why is the night sky dark?

The reason why this question is so important is because its answer can tell us about the distribution of stars and galaxies in the universe.

While we know the solution today for Olber's Paradox, it took until well into the 20th century for us to truly understand the nature of the Universe well enough to explain the answer to this question. In the rest of this lesson, you will find out how we came to understand the Universe and prove to ourselves the reason why the night sky is dark. There are 5 main reasons:

1. The Universe is not infinitely large, that is, it ends at some point.
2. Since light takes time to reach us, we can only see those objects that are near enough to us for their light to reach us. For example, we see the Sun as it was eight minutes ago and the Andromeda Galaxy as it was two million years ago, and so on. This means that the light from some more distant stars has not yet reached us.
3. Stars have only been shining for *a while*. The Universe that we can see is not infinitely old, but only about 14 thousand million years old.
4. Stars do not shine forever. They typically die after several thousand million years.
5. There are not enough stars in our Universe. If there were 10 million times more stars, there would be 10 million times more starlight! But our current starlight is too weak.

The study of the Universe is called **Cosmology**. **Cosmologists** study the structure and changes in the present Universe.

The Universe contains all of the **star systems**, **galaxies**, **gas** and **dust**, and all the **matter** and **energy** that exist. The universe also includes all of **space** and **time**.

The part of the entire Universe that we can see (because light from objects has had time to reach us) is called the **observable universe**.

The Earth is just a tiny speck in the universe. Our planet is surrounded by lots of space. Light travels across empty space. Light is the visible part of the electromagnetic spectrum.

✔ How do scientists learn about space?

Many scientists can touch the materials they study.

Most can do experiments to test those materials. Biologists can collect cells, seeds, or sea urchins to study in the laboratory.

Physicists can test the strength of metal or smash atoms into each other.

Geologists can chip away at rocks and test their chemistry.

What can astronomers use to study space? **Astronomers use the light and other energy that comes to us to gather information about the universe.**

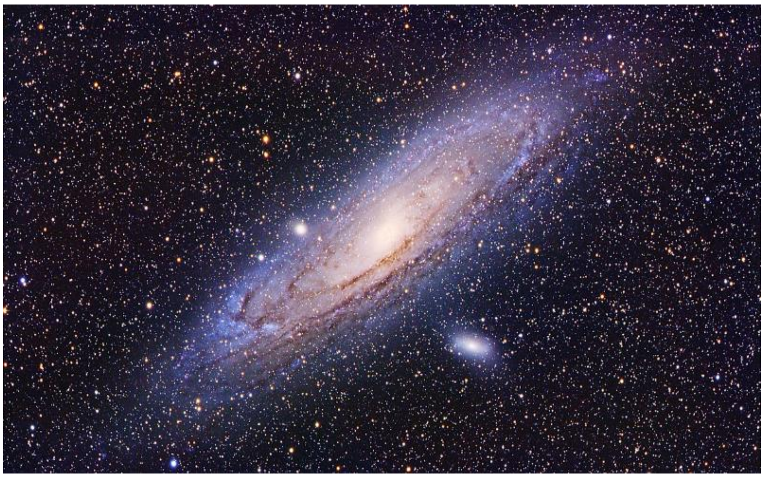


Figure 10.2 *Andromeda Galaxy*

This is the Andromeda Galaxy as it appeared 2.5 million years ago**. Why is the light so old?**

✔ The Speed of Light

In space, light travels at about **300,000,000 metres per second**.

How fast is that? If you travelled around the Earth at the speed of light, you would complete a journey around our planet 7.5 times in just one second.

Even light from the nearest star, our Sun, takes about eight minutes to reach the Earth.

✔ Light-Year and Parsec

We need a really big unit to measure distances out in space because distances between stars are so great.

– **A light-year, 9.5 trillion kilometres, is the distance that light travels in one year**. That’s a long way! Out in space, it is actually a pretty short distance.

- **A parsec (pc)** is equal to **3.26 light-years or roughly 31 trillion kilometres.** Multiples of parsecs are used to express the distances at which very distant objects in the Universe are, for example the **megaparsecs (Mpc).**

  Proxima Centauri is the closest star to us after the Sun. This nearest neighbour is **4.22 light-years away**. That means the light from Proxima Centauri takes 4.22 years to reach us.

  Our galaxy, the **Milky Way Galaxy**, is about 100,000 light-years across. So, it takes light 100,000 years to travel from one side of the galaxy to the other! It turns out that even 100,000 light years is a short distance.

  The most distant galaxies we have detected are more than 13 billion light-years away. That's over a hundred-billion-trillion kilometres!

✔ **Looking Back in Time**

When we look at stars and galaxies, we are looking over vast distances.

More importantly, we are also looking back in time. When we see a distant galaxy, we are actually seeing how the galaxy used to look.

For example, the Whirlpool Galaxy is about 23 million light-years from the Earth. When you see an image of the galaxy what are you looking at?

Figure 10.3
The Whirlpool Galaxy

You are looking at the galaxy as it was 23 million years ago!

Since scientists can look back in time, they can better understand the Universe's history.

<u>Earth Orbits a Star</u>

Certainly, no one today doubts that the **Earth orbits a star, the Sun.**

Photos taken from space, observations made by astronauts, and the fact that there has been so much successful space exploration that depends on understanding the structure of the solar system all confirm it.

But in the early 17th century saying that the Earth orbited the Sun rather than the reverse could have got you tried for heresy, as it did Galileo.

Let's explore the evolution of the idea that the Earth orbits the Sun.

The Geocentric Universe

To an observer, the Earth appears to be **the centre of the universe**.

That is what the ancient Greeks believed. This view is called the **geocentric model**, or the "**Earth-centred**" model, of the universe.

In the **geocentric model**, the sky, or heavens, are a set of spheres layered on top of one another.

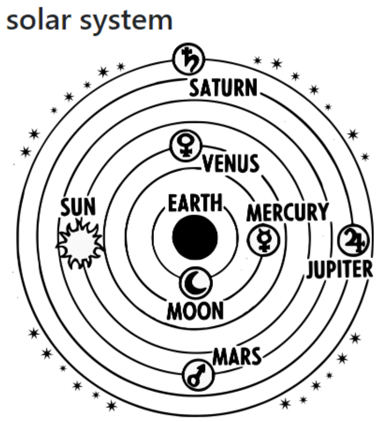


Figure 10.4
Geocentric model

Each object in the sky is attached to a sphere and moves around Earth as that sphere rotates. From the Earth outwards, these spheres contain the Moon, Mercury, Venus, the Sun, Mars, Jupiter, and Saturn. An outer sphere holds all the stars. Since the planets appear to move much faster than the stars, the Greeks placed them closer to the Earth.

The geocentric model explained why all the stars appear to rotate around the Earth once per day. The model also explained why the planets move differently from the stars and from each other. One problem with the geocentric model is that some planets seem to move backwards (in retrograde) instead of in their usual forward motion around the Earth.

The Heliocentric Universe

At the beginning of the 16th century A.D., **Nicolaus Copernicus** proposed that the **Earth and all the other planets orbit the Sun**.

With the Sun at the centre, this model is called the **heliocentric model**, or "**sun-centred**" model. Although Copernicus' model was simpler, it still did not perfectly describe the motion of the planets.

Johannes Kepler solved the problem a brief time later when he determined that the planets moved around the Sun in **ellipses** (ovals), **not circles**. Kepler's model matched the observations perfectly.

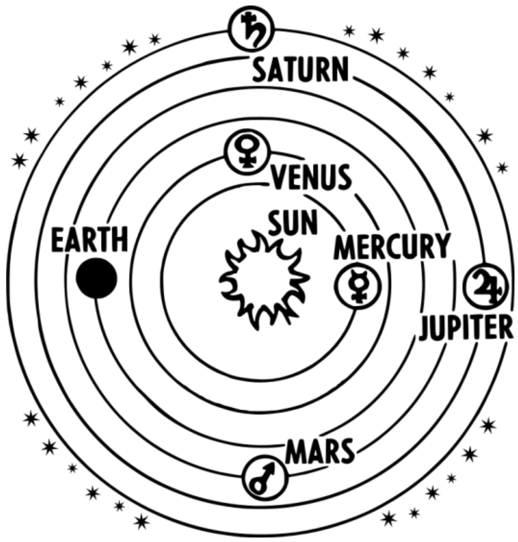


Figure 10.5
Heliocentric model

The heliocentric model did not catch on right away.

When **Galileo Galilei** first turned a telescope to the heavens in 1610, he made several striking discoveries. Galileo discovered that the planet Jupiter has moons orbiting it. This provided the **first evidence that objects could orbit something besides the Earth.**

Galileo's discoveries caused many more people to accept the heliocentric model of the universe, although Galileo himself was found guilty of heresy. The shift from an Earth-centred view to a Sun-centred view of the universe is referred to as the **Copernican Revolution**.

2. THE BIG BANG THEORY

The **Big Bang theory** is the most widely accepted cosmological explanation of how the Universe came to be formed.

If we start at the present and go back into the past, the Universe is contracting — getting smaller and smaller. What is the end result of a contracting Universe?

According to the Big Bang theory, **the Universe began about 13.7 billion years ago**. Everything that is now in the Universe was **squeezed into a very small volume**. Imagine all of the known Universe in a single, hot, chaotic mass. **An enormous explosion** — a **big bang** — caused the Universe to start **expanding rapidly**.

All the matter and energy in the Universe, and even space itself, came out of this explosion.

Figure 10.6

What came **before the Big Bang**? There is no way for scientists to know since there is no remaining evidence.

After the Big Bang

In the first few moments after the Big Bang, the universe was **unimaginably hot and dense**.

As the universe **expanded**, it became **less dense and began to cool**. After only a few seconds, **protons, neutrons, and electrons were able to form**.

After a few minutes, those subatomic particles came together to create **hydrogen**.

Energy in the universe was great enough to initiate **nuclear fusion**, and **hydrogen nuclei were fused into helium nuclei**.

The **first neutral atoms** that included electrons did not form until around 380,000 years later.

Dense clumps of matter held close together by **gravity** were spread around.

Eventually, these clumps formed countless trillions of **stars**, billions of **galaxies**, and other structures that now form most of the **visible mass of the universe.**

How do astronomers know the universe is expanding?

Doppler effect

The **Doppler effect** is a change in some properties of waves, wavelength, and frequency (light and sound are waves). It is caused by the change in distance between the thing creating the wave (causer) and whatever is measuring, seeing, or hearing the wave (watcher or observer).

Wavelength is **the measured distance between two identical points on two back-to-back waves**.

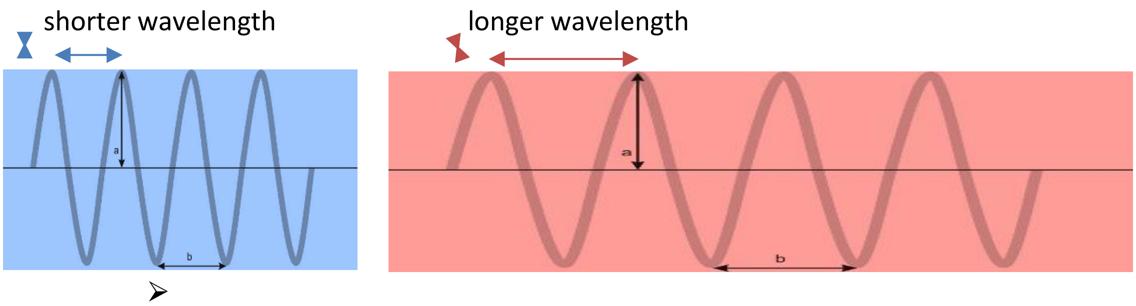


Figure 10.7

Different wavelengths of light appear to our eyes as assorted colours. **Shorter wavelengths appear as blue or violet, and longer wavelengths appear as red**.

- If the observer and the creator of the wave **get closer**, the wavelength is shorter.
    - For **light**, this causes a shift in colour towards the blue end of the spectrum called a blue shift. **The faster something is moving towards us, the greater the blue shift**.
    - For **sound**, this causes the sound to become higher in pitch

- If the distance between the observer and the creator **gets longer**, the wavelength is longer.
    - For **light**, this causes a shift towards the red end of the spectrum called a red shift, **the faster something is moving away, the greater the red shift.**
    - For **sound**, this causes the sound to become **lower in pitch**.

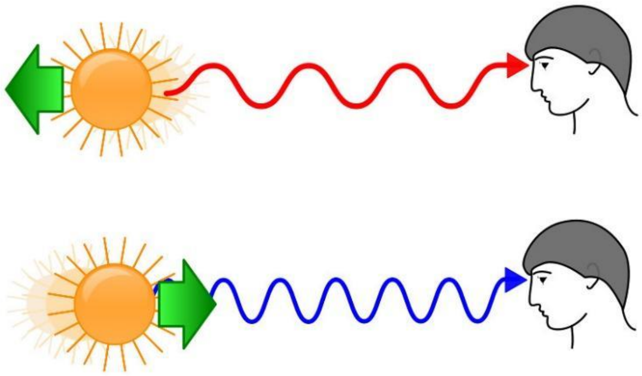


Figure 10.8

The picture above is a good starting point, so look at it again, afterwards you understand more about these shifts, as it will make more sense to you.

It is all about wavelengths for both Redshifts & Blueshifts. **Wavelengths expanding for a Redshift, and wave lengths reducing for a Blueshift.**

Light behaves like a wave, so light from a luminous object undergoes a Doppler-like shift if the source is moving relative to us.

In 1929, the astronomer **Edwin Hubble** changed our idea of the Universe with two discoveries, showing first that the Universe was much larger than previously thought, and second, that it is expanding, getting larger and larger all the time. M**ost galaxies are moving away from us**.

Light from these galaxies is shifted to longer (and this means redder) wavelengths - in other words, it is 'red-shifted'.

3. <u>SUN, STARS AND GALAXIES</u>

A **galaxy** is a **group of stars and other space stuff**, like interstellar gas and dust. The stars tend to spin around a centre of high gravity, like the planets spin around the Sun in the Solar System.

Galaxies are huge and can have trillions of stars. Each star can often have **its own planetary systems**.

As big as galaxies are, they are generally separated by large areas of empty space. There are even clusters of galaxies that are separated by even larger areas of space. Scientists think there are over 100 billion galaxies. **The Universe is huge!**

Our galaxy, the Milky Way

Figure 10.9

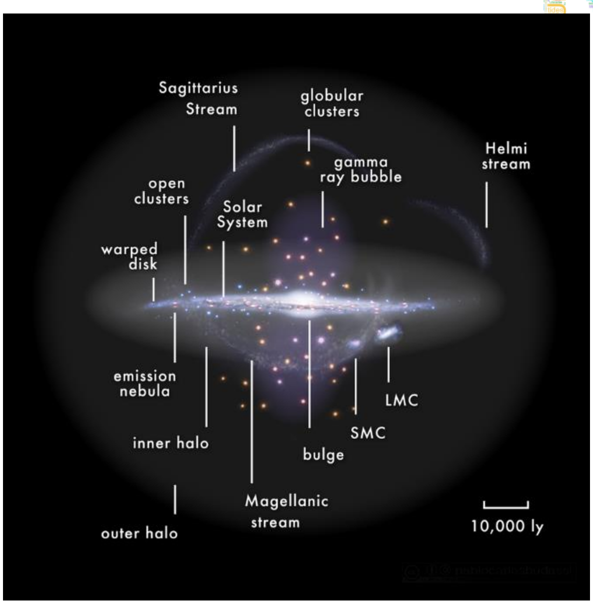


Figure 10.10

Two views of the Milky Way

Our galaxy**, the Milky Way Galaxy, is a large spiral system holding several hundred billion stars, one of which is the Sun. The Earth is just another planet orbiting just another star in a galaxy like many others in the Universe.**

Star Power

The **Sun** is the Earth's major source of energy, yet the planet only receives a small portion of its energy. The Sun is just an ordinary star.

Many stars produce much more energy than the Sun. The energy source for all stars is **nuclear fusion**.

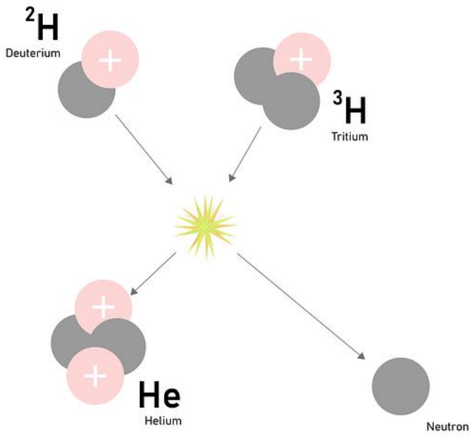


Figure 10.11

nuclear fusion

Nuclear Fusion

Stars are made mostly of **hydrogen** and **helium**, which are packed so densely in a star that the pressure is great enough in the star's centre to initiate nuclear fusion reactions.

In a **nuclear fusion reaction, the nuclei of two atoms combine to create a new atom.** Most commonly, in the star's core, **two hydrogen atoms fuse to become a helium atom.**

Although nuclear fusion reactions require a lot of energy to get started, once they get going, they **produce enormous amounts of energy**

The reaction is presented like this

$$2\ H \rightarrow He + Energy$$

Characteristics of stars

- **Brightness**: this depends on its composition, the amount of energy that the star releases and how far it is from the planet. The closer it is to the Earth, the brighter it looks.
- **Colour**: s**tars** have assorted colours, which are **indicators of temperature**.

  Stars exist in a range of colours: **red, orange, yellow, green, white, and blue** with red being the coolest and blue or bluish white being the hottest.

4. THE SOLAR SYSTEM

Since the time of Copernicus, Kepler, and Galileo, we have learned a lot more about our solar system. Astronomers have discovered two more planets (Uranus and Neptune), five dwarf planets (Ceres, Pluto, Makemake, Haumea, and Eris), more than 150 moons, and many, many asteroids, comets, and other small objects.

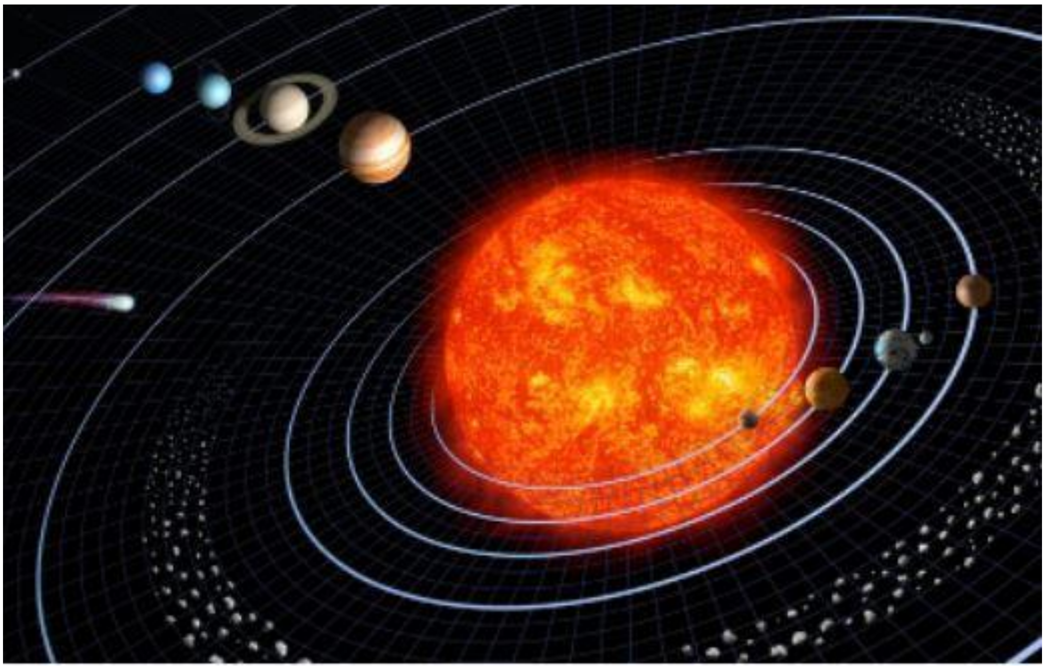


Figure 10.12
The Solar System

Our Solar System including the sun, planets, and many asteroids were all formed around 4.5 thousand million years ago. The Solar System was formed due to the **gravitational collapse of a giant cloud and dust** in space. This made the resulting disturbance in the cloud create clumps of gases due to gravity. Astronomers estimate that this happened because of the **explosion of a supernova star**.

Scientists believe that this interstellar cloud was absolutely massive and started the contraction of most molecules in the centre. So, a major part of this cloud and dust at the centre **formed the Sun**.

Other clumps of clouds and dust **formed the planets and smaller bodies** in the Solar System, in which the majority of mass **formed the planet Jupiter**.

Components of the Solar System

The Solar System is made up of:

- **The Sun**: although the Sun is just an average star compared to other stars, it is by far the largest object in the Solar System. The Sun is more than 500 times the mass of everything else in the Solar System combined! The table below gives data on the sizes of the Sun and planets relative to the Earth.

Sizes of Solar System Objects Relative to Earth

Object	Mass (Relative to Earth)	Diameter of Planet (Relative to Earth)
Sun	333,000 Earth's mass	109.2 Earth's diameter
Mercury	0.06 Earth's mass	0.39 Earth's diameter
Venus	0.82 Earth's mass	0.95 Earth's diameter
Earth	1.00 Earth's mass	1.00 Earth's diameter
Mars	0.11 Earth's mass	0.53 Earth's diameter
Jupiter	317.8 Earth's mass	11.21 Earth's diameter
Saturn	95.2 Earth's mass	9.41 Earth's diameter
Uranus	14.6 Earth's mass	3.98 Earth's diameter
Neptune	17.2 Earth's mass	3.81 Earth's diameter

The **temperature** on the surface of the Sun is about **5,600 Celsius**.

The temperature rises from the surface of the Sun inward towards its very hot centre where it reaches about 15,000,000 Celsius.

The Sun's temperature also rises from the surface outward into the solar atmosphere. The uppermost layer of the solar atmosphere, called the **corona**, reaches temperatures of millions of degrees. The corona is the bright halo of light that can be seen during a total Solar eclipse.

The Sun is mostly composed of the elements hydrogen (H) and helium (He). By mass, the composition of the sun is **92.1% hydrogen and 7.9% helium**. Various elements make up less than 0.1% of the Sun's mass (oxygen, carbon iron and other elements).

- **Planets and satellites**: The planets orbit the Sun in an elliptical orbital plane, whereas satellites orbit the planets. The planets are divided into three groups:
    - **Rocky planets**: Mercury, Venus, Earth, and Mars.
    - **Gas giants**: Jupiter, Saturn, Uranus, and Neptune.
    - **Dwarf planets**: Pluto, Ceres, Eris, and others.

- **The Asteroid Belt**. This is a **donut-shaped region** in the Solar System, located between the orbits of the planets Jupiter and Mars, where many small bodies orbit our sun. It contains a great many **solid, irregularly shaped bodies**, of many sizes, but much smaller than planets, called **asteroids** or minor planets.

- **The Kuiper Belt**. This is located just past Neptune, on the same orbital plane as the planets (Pluto is considered one of them). It is similar to the asteroid belt, a **donut-shaped region of icy bodies** beyond the orbit of Neptune. But it is far larger—20 times as wide and 20–200 times as massive.

- **The Oort Cloud**. The Oort Cloud is the most distant region in our solar system.

  Unlike the orbits of the planets and the Kuiper Belt, which lie mostly in the same flat disk around the Sun, the Oort Cloud is believed to be a **giant spherical shell** surrounding the rest of the solar system. It is like a big, thick-walled bubble of **icy pieces of space debris** the sizes of mountains and sometimes larger. The Oort Cloud might contain billions, or even trillions, of objects.

Because the orbits of long-period comets are so extremely long, scientists suspect that the **Oort Cloud is the source of most of those comets.**

Except for the Sun, no object in the Solar System emits its own light.

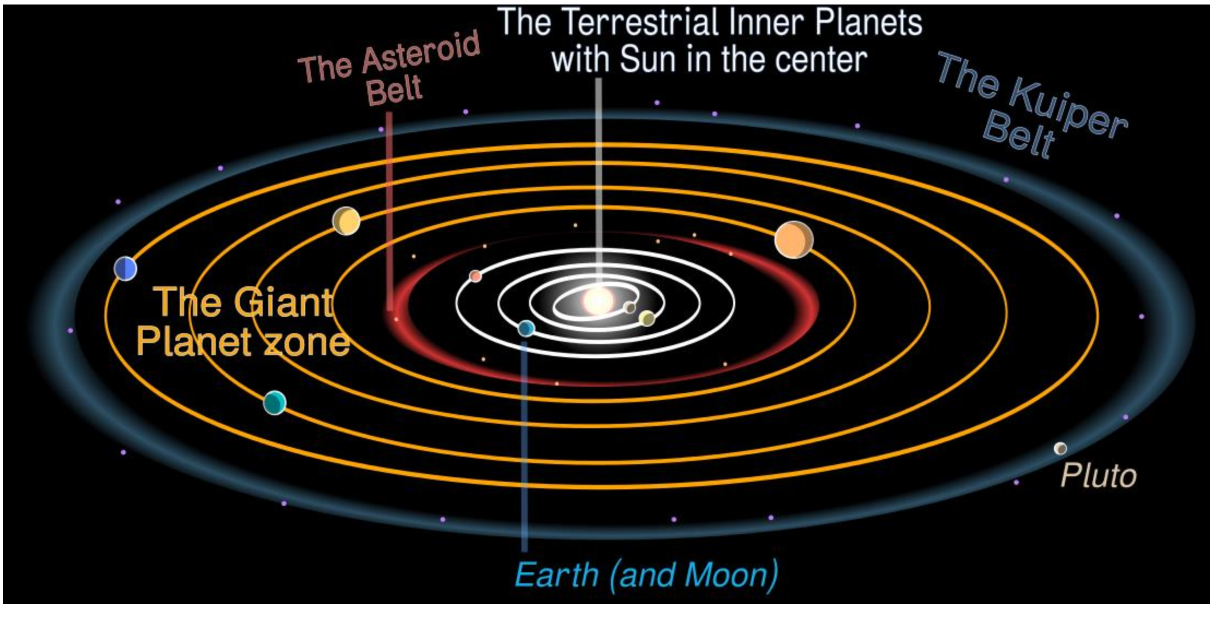


Figure 10.13

Orbits and Rotations

Distances in the Solar System are often measured in **astronomical units (AU).**

One astronomical unit is defined as the distance from the Earth to the Sun. 1 AU equals about 150 million km.

The following table shows the distances to the planets (the average radius of orbits) in AU.

The table also shows **how long it takes each planet to spin on its axis** (**the length of a day**) and **how long it takes each planet to complete an orbit** (**the length of a year**); in particular, notice how slowly Venus rotates compared to the Earth.

Distances to the Planets and Properties of Orbits Relative to Earth's Orbit

Planet	Average Distance from Sun (AU)	Length of Day (In Earth Days)	Length of Year (In Earth Years)
Earth	1.00	1.00	1.00
Mars	1.52	1.03	1.88
Jupiter	5.20	0.41	11.86
Saturn	9.54	0.43	29.46
Uranus	19.22	0.72	84.01
Neptune	30.06	0.67	164.8

Most of the objects in the Solar System share some characteristics, which have to do with the origin and evolution of the actual Solar System. Here are two of them:

- ✔ **Revolution.**

Our 8 planets, asteroids, comets, and some other solar system bodies revolve around the sun in an orbit.

This is due to the explosion and gravitational collapse of a giant cloud forming a system called the solar system in which our sun, 8 planets and their moons, dwarf planets and their moons, asteroids, and other bodies exist. Initially, these bodies have **velocity due to the explosion** in a certain direction.

The **Sun's gravity** pulls these planets towards the Sun's centre, but the **velocity of these planets** is perpendicular to the force of the Sun's pull. This makes an equilibrium between the force of the Sun's gravitational pull and forces developed by the planet's initial velocity.

All the planets, seen from the Celestial North Pole, move anti-clockwise around the Sun (in the opposite direction to the hands of a clock).

A **year** is the period of time required for one planet to fully travel around the Sun. For the Earth, the period is about $365\,^{1}/_{4}$ days.

- **Rotation.**

Most planets rotate on an **axis**, which is almost perpendicular to the plane of its orbit around the Sun.

For Uranus and Pluto, the rotational axes are titled, almost flat to their orbital planes. This means instead of rotating sideways like other planets, they rotate top to bottom!

Most planets in our solar system, including the Earth, rotate anti-clockwise, but Venus and Uranus are said to have a retrograde or clockwise rotation around their axes.

A **day** is the time a planet takes to rotate fully on its axis.

Eclipses

- **Solar Eclipses**

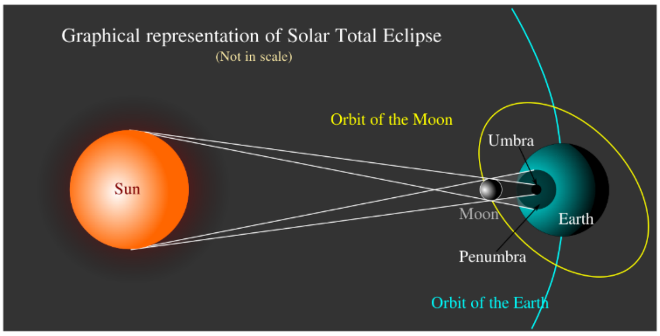


Figure 10.14

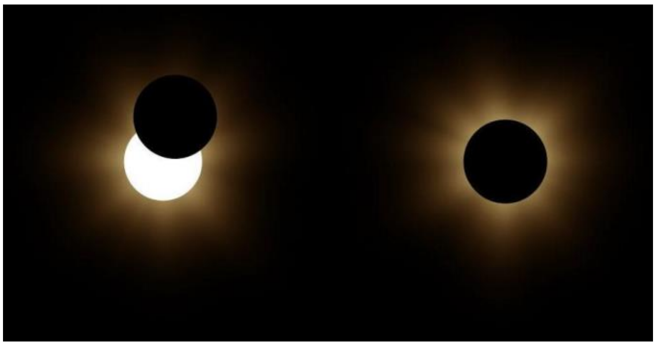


Figure 10.15

*A **solar eclipse** occurs when the **new Moon passes directly between the Earth and the Sun.***

This casts a shadow on the Earth and **blocks the Earth's view of the Sun**.

A **total solar eclipse** occurs when **the Moon's shadow completely blocks the Sun,** as you can see in the picture.

When only a portion of the Sun is out of view, it is called a **partial solar eclipse**. Solar eclipses are rare and usually only last a few minutes because the Moon casts only a small shadow.

- **Lunar Eclipse**

A **lunar eclipse occurs when the full moon moves through the Earth's shadow**, which only happens when the **Earth is between the Moon and the Sun and all three are lined up in the same plane.**

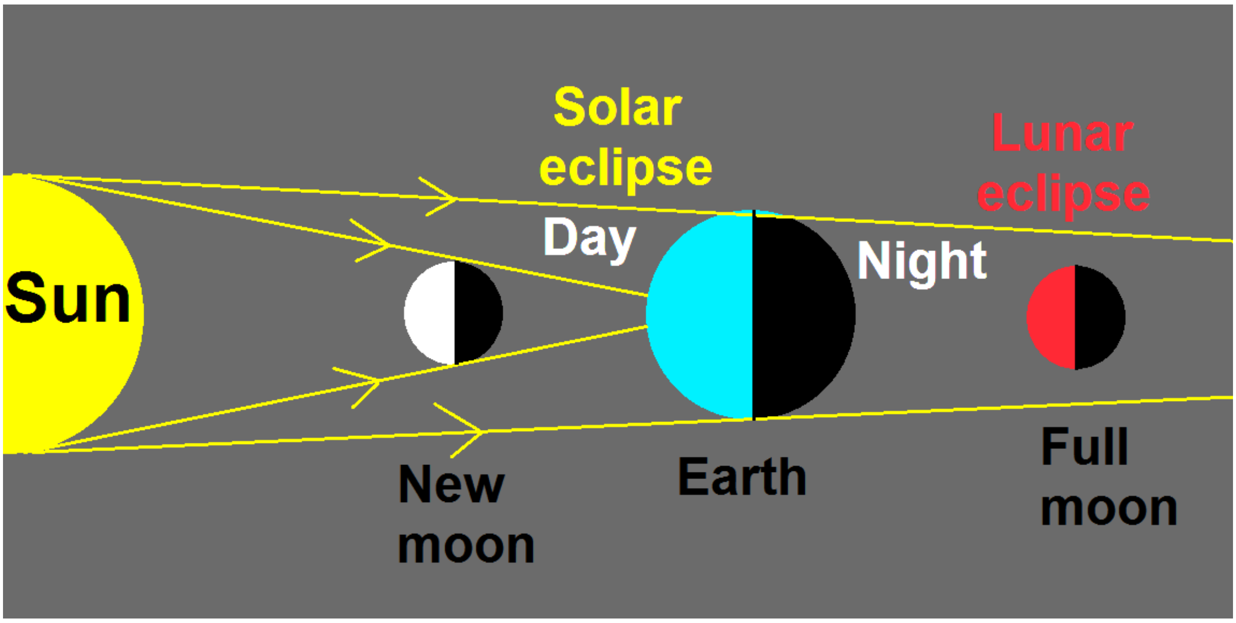


Figure 10.16
Solar eclipse and lunar eclipse

A total lunar eclipse occurs when **the Earth comes between the Sun and the Full Moon and blocks the Sun's direct rays from lighting up the Moon.**

A partial lunar eclipse happens when **the Earth moves between the Sun and the Full Moon, but they are not precisely aligned. Only part of the Moon's visible surface moves into the dark part of the Earth's shadow.**

Figure 10.17
Partial lunar eclipse

Lunar eclipses are more easily observed than solar eclipses, as they can be viewed with the naked eye by any observer standing where the Moon is above the horizon.

As such, a total eclipse can be seen from any given location — on average — once every 2.5 years.

Important reminder: **Never look directly at the Sun, even during a total solar eclipse, without protection such as verified eclipse glasses as serious and permanent eye damage can result**.

Seasons, equinoxes, and solstices

We divide up the year into four seasons: **spring**, **summer**, **autumn**, and **winter**. Each season lasts 3 months with summer being the warmest season, winter being the coldest, and spring and autumn coming in between.

Every **season** has a **beginning**, and those beginnings are the **solstices** and the **equinoxes**.

Why do seasons occur?

Seasons are caused because of the Earth's changing relationship to the Sun.

The Earth travels around the Sun, called an **orbit**, once a year or every 365 days. As the Earth orbits the Sun, the a**mount of sunlight each location on the planet gets everyday changes slightly. This change causes the seasons.**

Not only does the Earth revolve around the Sun every year, but the Earth rotates on its axis every 24 hours. This is what we call a day.

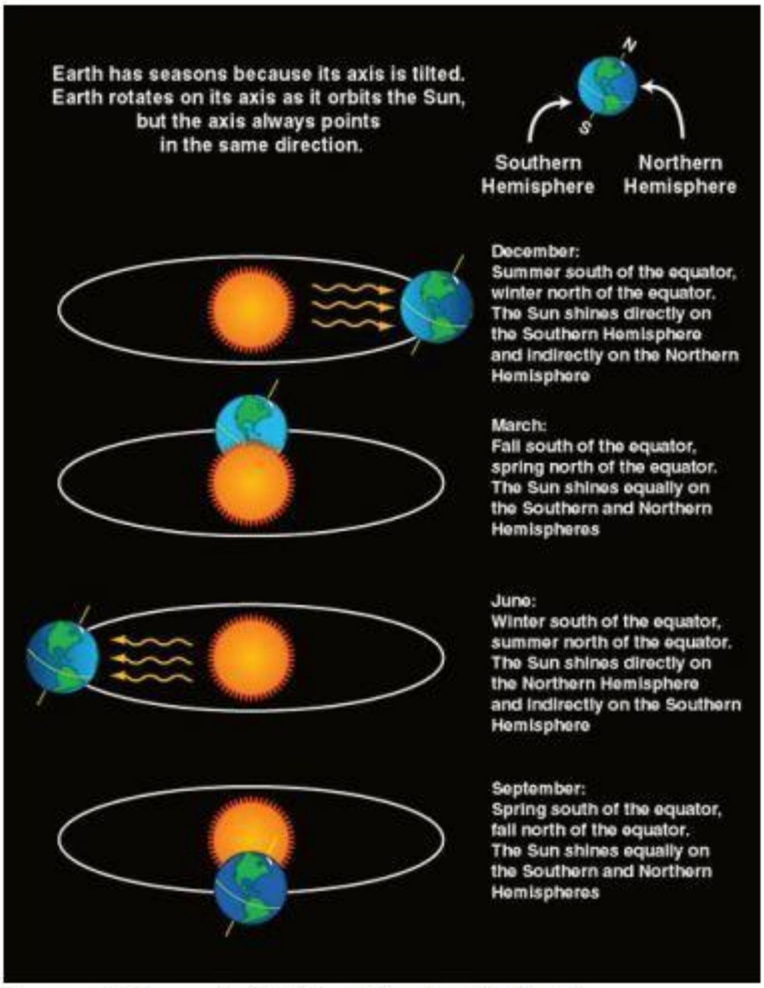


Image credit: Seasons by NASA Space Place is public domain

Figure 10.18

However, the Earth does not rotate in a straight up and down manner relative to the Sun. It is **slightly tilted** from its orbital plane with the Sun.

The tilt has two major effects: the angle of the Sun to the Earth and length of the days.

– For half of the year the Earth is tilted such that the North Pole is more pointed towards the Sun.
– For the other half, the South Pole is pointed at the Sun.

When the North Pole is angled towards the Sun, the days on the northern part of the planet (north of the equator) **get more sunlight** or longer days and shorter nights. With longer days the northern hemisphere heats up and gets summer.

As the year progresses, the Earth's tilt changes to where the North Pole is pointing away from the Sun producing winter.

The **astronomical definition of the seasons** relates to **specific points in the Earth's journey around the sun**.

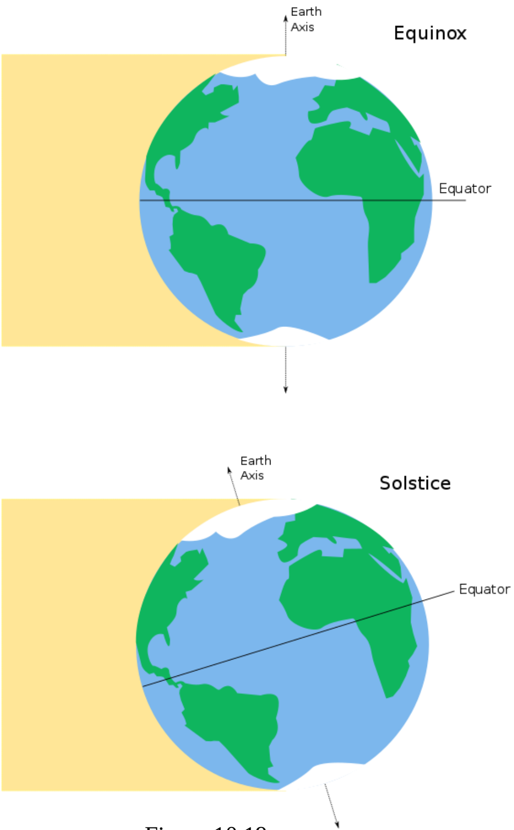


Figure 10.19

The **summer and winter solstice**, the **longest and shortest day of the year**, occurs when **Earth's axis is either closest or farthest from the sun**.

- The **summer solstice in the northern hemisphere occurs around June 21**, the same day as the winter solstice in the Southern Hemisphere.
- **The south's summer solstice occurs around December 21**, the winter solstice for the north.
- In both hemispheres, the summer solstice marks the first day of astronomical summer, while the winter solstice is considered the first day of astronomical winter.

Equinoxes are another significant day during the Earth's journey around the sun.

- On these days, **the planet's axis is pointed parallel to the Sun**, rather than towards or away from it.
- **Day and night during the equinoxes are supposed to be close to equal**.
- **The spring, or vernal, equinox for the northern hemisphere takes place around March 20**, the same day as the south's autumnal equinox.

- The vernal equinox in the southern hemisphere occurs around September 20, when people in the north celebrate the autumnal equinox.
- The vernal equinox marks the first day of astronomical spring for a hemisphere, while the autumnal equinox ushers in the first day of autumn.

5. THE EARTH-MOON SYSTEM

The Earth's Moon is the only place beyond the Earth where humans have set foot, so far.

The brightest and largest object in our night sky, the Moon makes the Earth a more livable planet by moderating our home planet's wobble on its axis, leading to a relatively stable climate. It also causes tides, creating a rhythm that has guided humans for thousands of years. The Moon was likely formed after a Mars-sized body collided with the Earth.

The Earth's Moon is the fifth largest of the 200+ moons orbiting planets in our solar system.

The Earth's only natural satellite is simply called "the Moon" because people did not know other moons existed until Galileo Galilei discovered four moons orbiting Jupiter in 1610.

The Moon is the Earth's only natural satellite. It travels around the Earth at a distance of about 385,000 kilometres.

The Moon has a solid, rocky surface, which is cratered and pitted from impacts by asteroids, meteorites, and comets.

The Moon has a very thin and tenuous atmosphere called an exosphere, which is not breathable. The Moon's weak atmosphere and its lack of water cannot support life as we know it.

Phases of the Moon

We always see the same side of the Moon, because as the Moon revolves around the Earth, the Moon rotates so that the same side is always facing the Earth.

But the Moon still looks a little different every night.

Sometimes the entire face glows brightly.

Sometimes we can only see a thin crescent.

Other times the moon seems to disappear entirely.

As the bright parts of the Moon appear to change shape during the month, each stage of the change is called a **phase**, and each phase carries its own name.

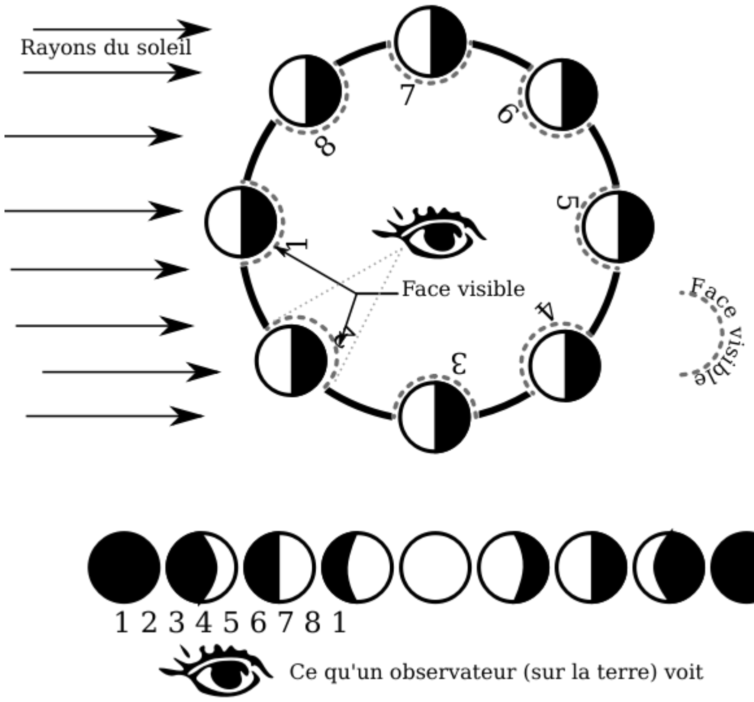


Figure 10.20
Phases of the Moon

This chart shows why this happens.

The centre ring shows the Moon as it revolves around the Earth, as seen from above the North Pole. Sunlight illuminates half the Earth and half the Moon at all times. But as the Moon orbits the Earth, at some points in its orbit the sunlit part of the Moon can be seen from the Earth, and at other points, we can only see the parts of the Moon that are in the shade. The outer ring shows what we see on the Earth during each corresponding part of the Moon's orbit.

<u>The tides</u>

Tides are the rise and fall of the ocean levels. They are caused by the gravitational pull of the Sun and Moon as well as the rotation of the Earth.

The picture shows the Moon´s (and Sun´s) differential attraction on various parts of the Earth. This is because all parts are not equally distant from the Moon, nor are they all in exactly the same direction from the Moon.

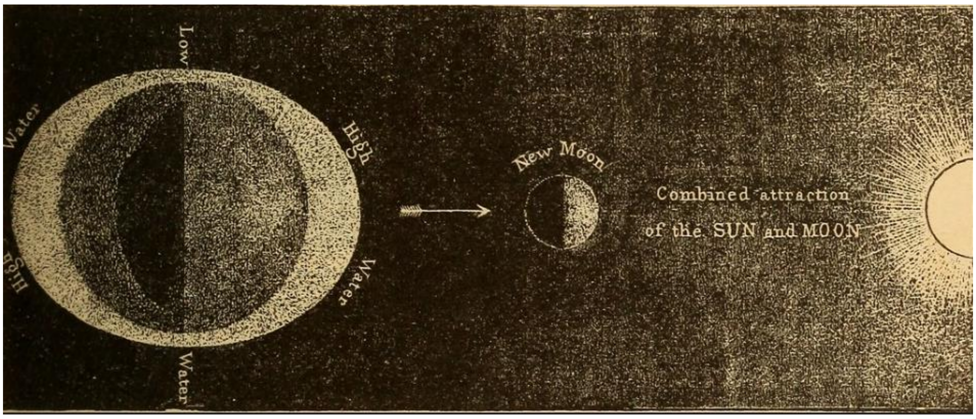


Figure 10.21

The actual tides we experience are a combination of **the larger effect of the Moon and the smaller effect of the Sun**. Ocean tides are complicated by the additional effects of the Sun and by the shape of the coasts and ocean basins.

When the Sun and Moon are lined up (at new moon or full moon), the tides produced reinforce each other and so are greater than normal. These are called **spring tides** (the name is connected not to the season but to the idea that higher tides "spring up").

Spring tides are approximately the same, whether the Sun and Moon are on the same or opposite sides of the Earth, because tidal bulges occur on both sides.

When the Moon is at first quarter or last quarter (at right angles to the Sun's direction), the tides produced by the Sun partially cancel the tides of the Moon, making them lower than usual. These are called **neap tides**.

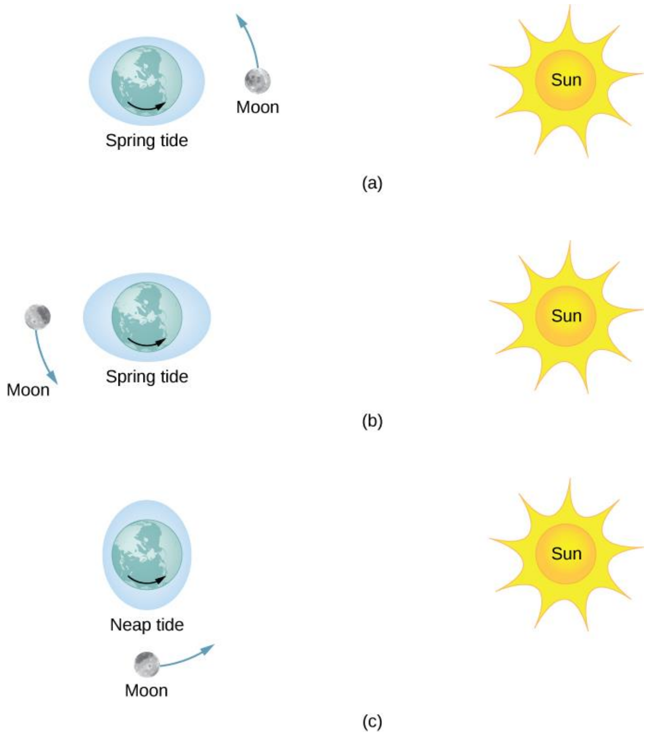


Figure 10.22

The picture shows tides caused by different alignments of the Sun and Moon: (a) (b) In spring tides, the Sun's and Moon's pulls reinforce each other. (c) In neap tides, the Sun and the Moon pull at right angles to each other, and the resulting tides are lower than usual.

6. THE FORCE OF GRAVITY. RULING THE UNIVERSE

Gravity is a force between two masses, so gravity exists wherever there is mass. To discover when gravity started to exist, we need to understand what mass is, and when it started to exist.

Let's dive right in: "mass" is what we use to measure how much "matter" there is. Scientists use the term "matter" to describe things like stars, planets, oceans, rocks, molecules, atoms, particles like electrons and protons that make up atoms, and even the particles that make up electrons and protons.

Figure 10.23

7. THE EARTH-MOON SYSTEM

So, when did mass first appear? Based on our best understanding of the physics of the Universe, the first mass was created in the form of tiny particles (a LOT of them) right after the beginning of the universe itself, about 13.7 billion years ago.

The creation of matter happened so fast after the creation of the universe that you could fit more than a million of those instants in the time it takes to blink an eye. And from that moment, gravity was at work, pulling matter together, gathering atoms and molecules into dense clouds that eventually formed stars, galaxies, and planets.

Of course, there are many forces in nature, and gravity is only one of them. The other forces work on matter too, so there has always been a cosmic dance between the different forces in the universe, which makes it look how it does.

Gravity might be the force that we are all most familiar with because we have all felt it since the moment we were born, but actually compared to many of the other forces **it is not especially strong.**

But since gravity is found anywhere there is mass, it is basically everywhere, at all times.

The same gravity that keeps you on the ground here on the Earth also holds the Earth together, holds the Earth in orbit around the sun, and holds the Sun in orbit around the rest of the galaxy.

Gravity has existed for as long as the universe has, and it will keep existing, for as long as we do, and beyond.

Sir Isaac Newton was the first scientist to precisely define the gravitational force, and to show that it could explain both falling bodies and astronomical motions.

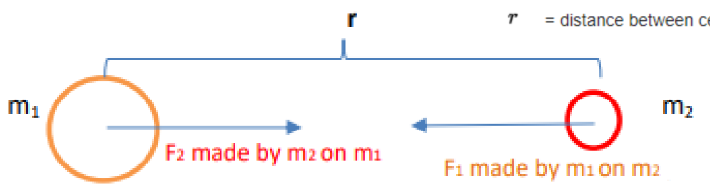
The gravitational force is relatively simple.

- It is always **attractive**,
- and it depends only on the **masses** involved and the **distance** between them.

Stated in modern language, **Newton's universal law of gravitation states that every particle in the universe attracts every other particle with a force along a line joining them. The force is directly proportional to the product of their masses and inversely proportional to the square of the distance between them.**

$$F = G\frac{m_1 m_2}{r^2}$$

F = force
G = gravitational constant
m_1 = mass of object 1
m_2 = mass of object 2
r = distance between centers of the masses



The magnitude of the force on each object (one has larger mass than the other) is the same

In this equation, the proportionality constant **G** is called the **Universal Gravitational Constant**, and its value is:

$G = 6{,}67 \times 10^{-11}$ N m²/kg²

The value of the constant G is tiny. This is why the gravitational force is tiny between objects with very little mass.

However, when planets, satellites and stars are involved, the correspondent masses are huge, and the effect of gravity becomes particularly important.

Gravitational force is relatively weak but becomes relevant when two bodies with large mass interact.

Why do objects fall?

The most remarkable and unexpected fact about falling objects is that, if air resistance and friction are negligible, then in any given location all objects fall toward the centre of Earth with the **same constant acceleration, no matter their mass.**

This experimentally determined fact is **unexpected**, because we are so accustomed to the effects of air resistance and friction that we expect light objects to fall slower than heavy ones.

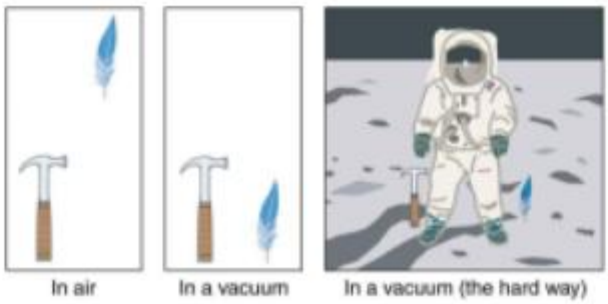


Figure 10.24

In the real world, air resistance can cause a lighter object to fall slower than a heavier object of the same size. A tennis ball will reach the ground after a hard baseball dropped at the same time

The force of gravity causes objects to fall towards the centre of the Earth.

The acceleration of free-falling objects is therefore called **acceleration due to gravity**.

Acceleration due to gravity is **constant**, which means we can apply the kinematics equations to any falling object where air resistance and friction are negligible.

This opens a broad class of interesting situations to us. Acceleration due to gravity is so important that its magnitude is given its own symbol, **g**. It is constant at any given location on the Earth and has the average value

The direction of the acceleration due to gravity is **downward (towards the Earth's centre).** In fact, its direction defines what we call **vertical**.

The force with which the Earth attracts an object can be calculated using both equations:

$$F = G\frac{m_1 m_2}{r^2}$$ **Newton´s Law of Universal Gravitation**

$$F = m_2\, a$$ **Newton´s Second Law of Motion**

F= force made by the Earth on the object

G= universal gravitational constant

m_1 = mass of the Earth = M

m_2= mass of the object

r= distance from the centre of the object to the centre of the Earth = Earth radius

As both equations share the same solution, $G\frac{M\, m_2}{r^2} = m_2\, a$

Eliminating the mass m_2, the mass of the object, on both sides of the equation, we get:

$$a = G\,\frac{M}{r^2} = g$$

To make it clear that this acceleration is due to gravity, it is usually called g.

If we substitute the values for G, the mass of the Earth and the Earth's radius:

$$g = 6{,}67 \times 10^{-11} \times \frac{6 \times 10^{24}}{(6{,}37 \times 10^{6})^2} = \mathbf{9{,}8\ m/s^2}$$

Al objects fall to the ground with the same acceleration regardless of their mass.

For this reason, they take the same time to reach the ground when dropped from the same height.

WEIGHT (W) The weight of an object is the measure of the force of gravity of an object. It is the gravitational force with which the Earth (or another astronomical object) attracts it.

W = m × g

W = $G\frac{Mm}{r^2}$

The object's mass is always the same, but its weight is different when moving from one astronomical object to another.

As you travel away from the Earth's surface, your mass stays the same, but your weight reduces as gravitational pull decreases.