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# Contents

# 1 Lecture 2

## 1.1 Biology

**Definition.** *Biology*
*Biology* is the study of the formation and evolution of life.

- Planetary science and astronomy yield context for life.
- Biological research is limited to Earth-based life, yielding poor context for possibilities of universal life.
- Understanding the conditions that led to life on Earth helps us identify potential locations for extraterrestrial life.

## 1.2 The Human Adventure

- The development of Astronomy is deeply intertwined with the development of civilisation and changes in society.
- Revolutions in astronomy have gone hand in hand with giant leaps in technology and science.
- Astronomy is the science that asks the deep question about the origins of humanity.

## 1.3 Modern View of the Universe

- What is our physical place in the universe?
- What is known about planets, stars, galaxies, space and time?
- How do we know what we know?

## 1.4 Universal Objects

**Definition.** *Star*
A *star* is a large, glowing ball of mostly hydrogen gas that generated heat and light by nuclear fusion. Larger stars generally have shorter lifespans.

**Note.** Hydrogen is the lightest and most abundant element in the universe.

**Definition.** *Planet*
A *planet* is a moderately large object which orbits a star; it shines by reflected light. They may be rocky, icy, or gaseous in composition.

Pluto and the family of objects beyond Neptune are now called “dwarf planets”.

**Definition.** *Moon*
A *moon* is an object which orbits a planet—may also be referred to as a *satellite*.

**Definition.** *Asteroid*
An *asteroid* is a relatively small and rocky object which orbits a star. They usually do not have the mass (and thus the gravity) to be spherical in shape.

**Definition.** *Comet*
Comets are icy dust balls that get vaporised when they get too close to a star, leaving a bright trail in the sky. They usually originate outside the solar system.

**Definition.** *Solar (Star) System*
A star and all the material that orbits it, including planets, asteroids and comets, and all the moons that orbit those planets.

**Definition.** *Nebula*
A *nebula* is a cloud of gas that is gravitationally attracted to itself, and will eventually become a star (system). Like most things, it is mostly composed of hydrogen, but also contains small solid particulates of carbon and silicon.

**Definition.** *Galaxy*
An enormous "island of stars" far out in space, all held together by gravity and orbiting a common centre.

**Definition.** *Universe*
The sum total of all matter and energy; that is, everything within and between all galaxies.

**Definition.** *Astronomical Unit*
The (average) distance from the Earth to the Sun is 150 million km or 93 million miles, and is called an *astronomical unit.*

**Definition.** *Atom*
*Atoms* are the microscopic "building blocks" of all chemical elements—92 of which occur in nature.

## 1.5 Where Do We Come From?

- The first (and simplest) atoms (hydrogen and helium) were created during the *Big Bang*.
- More complex atoms (like carbon and oxygen) were created much later, inside stars.
- As stars age and die, they expel matter into space, which in turn forms new stars and planets.

## 1.6 Light is the Measure of All Things

- The speed of light is the absolute speed limit of the universe.
- As far as we know, there are no methods of travelling faster than light.

## 1.7 A Universe in Motion

- We are constantly moving in space—on "spaceship Earth". The earth rotates around its axis once per day, which results in a speed of around 1000 mph at the equator.

# 2 Lecture 3

The Earth is non-stationary—it is moving through space at extreme speeds. The universe is also expanding, and things are all getting further and further away from us. The reason that we aren't getting further and further away from the Earth is because gravity is usually enough to hold things together (when things are close enough).

**Note.** We are not in a particularly special place in the universe, nor are we at a special time.

## 2.1 Planetary Science

**Definition.** *Planetary Science*
*Planetary science* is the study of the creation and evolution of planetary bodies, moons, asteroids, comets, etc.

Studying solar system bodies investigates why life formed on some worlds, and not others.

- All the planets orbit the Sun in elliptic paths, all in the same plane.
- The tilt of the planet is the main reason for the seasons.

### 2.1.1 Annual Motion Definitions

**Definition.** *Ecliptic*
The *ecliptic* is the apparent path of the Sun through the sky.

**Definition.** *Equinox*
The *equinox* is where the ecliptic intersects the celestial equator.

**Definition.** *Solstice*
The *solstice* is where the ecliptic is farthest from the celestial equator.

**Definition.** *Zodiac*
The *zodiac* is the constellations which lie along the ecliptic.

## 2.2 The Parsec

**Definition.** *Parsec*
We define one *parsec* to be 3.26 light-years.

We can calculate the distance to a star by using the parallax effect, namely

$$\text{Distance in parsecs} = \frac{1}{\text{Parallax in seconds}}.$$

## 2.3 The Science of Astronomy

Copernicus proposed the heliocentric model in 1543, but his model was no more accurate than geocentric models, because he used perfect circles for the orbits. Tycho Brahe tried, but failed, to detect stellar parallax, so he thought Earth was at the centre of the solar system and other planets went around the Sun. He would go on to hire Johannes Kepler, who used Tycho's observations to discover the *truth* of planetary motion. Johannes Kepler first tried to use circular orbits, but a discrepancy led him to propose elliptical orbits.

## 2.4 Kepler's Laws

1. The orbit of each planet around the Sun is an ellipse.
2. As a planet moves around its orbit, it sweeps out *equal areas in equal times*.

   > **Note.** Planets move *faster* the closer they are to the Sun.

3. More distant planets orbit the Sun at slower *average* speeds, obeying the relationship

   $$p^2 = a^3,$$

   where $p$ is the orbital period (in years) and $a$ is the average distance from the Sun (in AU).

## 2.5 Galileo Discoveries

- Galileo showed that objects will stay in motion unless a force acts on them to slow them down.
- Galileo proved that there are imperfections on the celestial bodies: sunspots on the Sun, craters on the moon, etc.
- Galileo proved that stars are much further than Tycho thought, so the undetectable parallax was justified.
- There are objects that do not orbit the Earth (the moons of Jupiter).
- By observing the phases of Venus, he showed that Venus does not orbit the Earth.

## 2.6 Hallmarks of Science

1. Modern science seeks explanations for observed phenomena that rely solely on *natural* causes.
2. Science progresses through the creation and testing of models of nature that explain the observations as simply as possible.
3. A scientific model must make *testable predictions* about natural phenomena that would force us to revise/abandon the model if it does not agree with observations.

> **Definition.** *Scientific Theory*
> A *scientific theory* must:
>
> - Explain a wide variety of observations with a few simple principles.
> - Must be supported by a large, compelling body of evidence.
> - Must not have failed any crucial test of its validity.

# 3 Lecture 4

## 3.1 Describing Motion

**Definition.** *Kinematics*
We define *speed* to be the rate at which an object moves, given by

$$\text{speed} = \frac{\text{distance}}{\text{time}}.$$

*Velocity* is similar to speed, but also has a direction. *Acceleration* is *any* change in velocity (magnitude or direction). Both velocity and acceleration have magnitude and direction, so they are *vectors*.

## 3.2 Acceleration Due to Gravity

All falling objects near the Earth's surface accelerate at the *same* rate, independent of the mass of each object. On Earth, this has the value 9.8 $\text{m/s}^2$.

## 3.3 Momentum and Force

Linear momentum is given by the mass of an object times the velocity of that object, or

$$p = m \cdot v.$$

Newton found that a net force changes momentum. The difference between mass and weight is that mass is the amount of matter in an object, whereas weight is the force that acts upon an object.

## 3.4 Newton's Laws of Motion

Newton realised that the same physical laws that operate on Earth also operate in outer space.

1. An object moves at a constant velocity unless a net force acts to change its speed or direction.
2. Force is mass times acceleration, or $F = ma$. In other words, force is the rate of change of momentum: $F = \frac{\mathrm{d}p}{\mathrm{d}t}$.
3. Every force has an equal and opposite reaction force.

**Note.** Reaction forces act upon different objects.

## 3.5 The Gravitational Force

1. Every mass attracts every other mass.
2. Attraction is *directly* proportional to the product of their masses.
3. Attraction is *inversely* proportional to the square of the distance between their centres.

This is given by the equation

$$F_g = G\frac{M_1 M_2}{d^2},$$

where $G$ is a constant.

## 3.6 "Conservation" Laws

There are three important conservation laws:

- Conservation of linear momentum ($mv$)
- Conservation of angular momentum ($mvr$)
- Conservation of energy

The conservation of angular momentum is the reason why planets move slowly the further away they are from the Sun, and faster when they are closer. It is also the reason why clouds of gas (large $r$) eventually contract into spinning disks (smaller $r$).

### 3.6.1 Energy

- Energy makes matter move.
- Energy is conserved, but it can transfer from one object to another and change in form.
- All energy can be traced back to the Big Bang.

### 3.6.2 Types of Energy

- Kinetic Energy (motion) is given by the equation: $K.E. = \frac{1}{2}mv^2$.
- Radiative (light).
- Potential (or stored).

Energy is measured in Joules, and power is measured in Joules per second, or Watts.

### 3.6.3 Thermal Energy

Thermal energy is a sub-type of kinetic energy—the collective *kinetic energy* of many particles. It is related to temperature, but *not* the same. Temperature is the *average* kinetic energy of the many particles in a substance, not the sum.

**Note.** Absolute zero is the temperature when particles stop moving.

### 3.6.4 Gravitational Potential Energy

On Earth, it depends on the mass of an object ($m$), the strength of gravity ($g$), and the distance an object could potentially fall ($h$). Thus the gravitational potential energy is given by $U_g = mgh$.

## 3.7 Mass-Energy

Mass itself is a form of energy, given by $E = mc^2$, where $c$ is the speed of light.

- A small amount of mass can release a lot of energy.
- Concentrated energy can spontaneously turn into particles, for example particle accelerators.

# 4 Lecture 5

## 4.1 Formation of the Solar System

An object's orbit cannot change spontaneously—it can only change if it gains or loses *orbital energy*, the sum of kinetic and gravitational potential energy.

### 4.1.1 Kepler and Newton

Kepler's first two laws apply to *all* orbiting objects, not just planets. In addition to being elliptic (bound paths), orbits can be unbound (hyperbolic or parabolic). Newton's Law of gravity permits all of these orbits.

Newton generalised Kepler's Third Law, observing that:

If a small object orbits a larger one, and if you measure the smaller object's orbital period and average orbital radius, then you can calculate the mass of the larger object. This is given by the equation:

$$p^2 = \frac{4\pi^2}{G(M_1 + M_2)} a^3,$$

where $p$ is the orbital period, $a$ is the average orbital distance (between centres), and $M_1 + M_2$ is the sum of the object masses.

**Example.** *Kepler's Third Law (Generalised)*

- You can calculate the mass of the Sun from the Earth's orbital period and average distance (1 year and 1 AU, respectively).
- You can calculate the mass of Earth from the orbital period and average distance of *any* orbiting satellite, including the Moon.
- You can calculate the mass of Jupiter from the orbital period and orbital radius of any one of Jupiter's moons.

### 4.1.2 Changing an Orbit

Conservation of angular momentum holds, always—orbits change either due to friction or gravitational encounters with another object.

**Definition.** *Escape Velocity*
If an object gains enough orbital energy, it may *escape* (change from a bound to an unbound orbit). For the Moon, this *escape velocity* is about 2 km/sec, for Mars it is about 5 km/sec, and for the Earth, it's about 11.1 km/sec.

**Note.** Escape velocity depends on the mass of the Earth, not the mass of the object.

## 4.2 A Brief Tour of the Solar System

The planets are tiny in comparison to the Sun and the solar system is mostly empty space in between planetary orbits.

### 4.2.1 The Sun

- Contains over 99.8% of the solar system's mass.
- Made mostly of *ionized* Hydrogen and Helium gas (plasma).
- Converts 4 million tons of mass into energy each second.

- Its radius is 696000 km, approximately 108 times the radius of the Earth.

#### 4.2.2 Mercury

- Made of metal and rock; large *iron* core.
- Desolate, cratered like our Moon; long, tall, steep cliffs.
- Temperatures fluctuate drastically: from 425°C (day) to −170°C (night)

#### 4.2.3 Venus

- Nearly identical in size to Earth; surface hidden by thick clouds.
- Hellish conditions due to an extreme *greenhouse effect*.
- Even hotter than Mercury: 470°, both day and night.
- Atmospheric pressure is equivalent to 1 km depth in Earth's oceans.
- No oxygen, no water.
- Venus may have been habitable (had liquid water) for 3 billion years.

#### 4.2.4 Earth

- An oasis of life; bio-generated oxygen in the atmosphere.
- The only planet with liquid water in the solar system; about 3/4 of our surface is covered in water.
- A surprisingly large moon (1/4 radius, 1/80 mass).

#### 4.2.5 Mars

- Giant volcanoes, a huge canyon, polar caps, and more.
- Water flowed in the distant past; could there have been life?
- Thin atmosphere of carbon dioxide.
- Water probably flowed; surface habitable; 1 billion years.

#### 4.2.6 Jupiter

- Much farther from the Sun than the inner planets (5.2 AU).
- Very different composition—A large gas ball composed mostly of Hydrogen and Helium.
- No solid surface.
- Huge: 318 times Earth's mass and over 1000 times Earth's volume.
- Many moons and rings.

**Moons of Jupiter**

- Io: Yellowish, with active volcanoes all over.
- *Europa: Possible subsurface ocean; possible place to search for life.*
- Ganymede: Largest moon in the solar system—larger than Mercury.
- Callisto: a large, cratered "ice ball" with unexplained surface features.

#### 4.2.7 Saturn

- Giant and gaseous like Jupiter.
- Most spectacular rings of the 4 jovian planets.
- Many moons, including cloudy Titan.
- *Enceladus has a warm, salty ocean.*
- The **Cassini** spacecraft spent 10 years studying Saturn.

#### 4.2.8 Uranus

- Smaller than Jupiter or Saturn, but still much larger than Earth (4x).
- Made of Hydrogen and Helium gas, and hydrogen compounds ($H_2O$, $NH_3$, $CH_4$).
- Extreme axis tilt—nearly tipped on its "side". This causes extreme seasons during its 84 year orbit.
- It has moons and rings.

#### 4.2.9 Neptune

- Similar to Uranus (except for the axis tilt).
- Many moons, including unusual Triton (it orbits "backwards").
- Triton is larger than Pluto.

#### 4.2.10 Pluto and the Other Dwarf Planets

- Much smaller than other planets (0.18 Earth's radius).
- Icy, comet-like composition.
- Pluto's largest moon (Charon) is similar in size to Pluto itself.

In January 2006, the New Horizons probe was sent to investigate Pluto. It flew by Pluto on July 14, 2015. We now have incredible detail of Pluto's surface.

### 4.3 Clues to the Formation of the Solar System

- The Sun, planets, and large moons orbit and rotate in an organised way.
- There are two major planet types: small, rocky planets close to the Sun, and large, gaseous (jovial) planets further away from the Sun.

A successful theory of solar system formation must allow for exceptions to general rules, i.e.:

- Earth's relatively large moon.
- Uranus's odd tilt.

#### 4.3.1 Nebular Theory

According to the *nebular theory*, our solar system formed from a giant cloud of interstellar gas which also contained tiny solid grains of heavier elements.

The conservation of angular momentum caused the gas cloud to rotate faster and faster as it shrank (due to gravity). The many particles in the cloud collided with each other, flattening the cloud.

#### 4.3.2 The Formation of Planets

There are two types of planets because of temperature. Near the Sun, where it was extremely hot, only iron, nickel, and other heavy metals could condense out of the gas phase. Further away from the Sun, where it was cold, were the only regions where water, methane and ammonia to condense and make "ice". We call the border between these two areas the "frost line".

> **Definition.** *Planetesimals*
> Little pieces of matter that condensed out of the nebula.

> **Definition.** *Accretion*
> The assembly of planets from planetesimals due to gravity, with ice sticking pieces together, is called *accretion.*

> **Definition.** *Fragmentation*
> The process by which small, denser regions within the nebula can collapse more quickly than the rest.

There is further evidence for accretion:

- Asteroids are planetesimals that formed inside the frost line.
- Comets are planetesimals that formed outside the frost line.

Earth's moon was probably created when a large planetesimal crashed into the young Earth (nearly 4.5 billion years ago).

#### 4.3.3 Finding the Age of the Solar System

We find the age of rocks that compose a planet via radioactive dating (which works by calculating the proportion of a radioactive isotope). Each radioactive isotope has a *half-life*, the time it takes for approximately half of the isotope to decay into something stable.

Using radioactive dating, we have found meteorites that are approximately 4.6 billion years old, which is also about the age of the Sun (found via separate analysis).

# 5 Lecture 6

## 5.1 Light

- Is both a particle and a wave.
- Massless.
- Has energy.
- Photon energy = $h$(frequency) = $\frac{hc}{\lambda} = h\nu$, where $h$ is Planck's constant.
- Is oscillations of electric and magnetic waves.
- Light is produced when an electron is accelerated or oscillates.
- Electrons can absorb light, increasing their energy.

We can use the electron-volt (eV) to describe the energy of light. The electromagnetic spectrum, from highest to lowest energy: gamma, x-rays, ultraviolet, visible, infrared, microwaves, radio waves.

### 5.1.1 Composition of Matter

Electrons orbit the nucleus of an atom in an *electron cloud*. It is impossible to know exactly where an electron is and know its velocity. Electrons can only have set energy levels (quantized states).

### 5.1.2 Light and Matter

- Emission—Photons are produced.
- Absorption—Photons are consumed.
- Transmission—Photons pass through freely.
- Reflection or Scattering—Photons are redirected all in the same direction (reflection), or in random directions (scattering).

### 5.1.3 Three Types of Spectra

A *spectrum* is a plot of the intensity of light as a function of wavelength or energy. The laws of quantum physics tell us that energies in atoms are discrete, hence those lines. Distinct energy levels in atoms lead to distinct emission or absorption lines—photons are absorbed or emitted, moving electrons up or down an energy state.

**Chemical Fingerprints**

- Ever atom, ion, and molecule has a unique spectral "fingerprint" because of the unique set of electron energy level.
- This gives off a nique pattern of emitted or absorbed wavelengths of light.
- We can identify the chemicals in a gas cloud by looking at the absorption lines.

## 5.2 Thermal Radiation

- Nearly all large or dense objects emit thermal radiation.
- An object's thermal radiation spectrum depends on only one property—temperature.
- Electromagnetic radiation produced this way has a continuous spectrum of energy with a peak at one wavelength.

At low temperatures the emitted radiation is infrared, which our eyes cannot see. As heat increases, things turn blue-white.

### 5.2.1 Two Properties of Thermal Radiation

- Hotter objects emit more light at all frequencies *per unit area* (higher intensity).
  Stefan-Boltzmann Law: Luminosity per square metre = constant $\cdot T^4$.
- Hotter objects emit photons with a higher average energy.
  Wien's Law: $T(K) = \frac{3000000}{\lambda}$, where $\lambda$ is the wavelength in nanometres.

**Things to Know**

- All objects emit a thermal spectrum.
- The shape of the spectrum is the same, but shifts to shorter wavelengths for hotter objects.
- The shape is *independent of the composition*.
- All stars can be considered to emit a thermal spectrum at a temperature $T$.

We can use light to tell us the *speed* of a distant object, using the Doppler Effect. The frequency changes when the source object is moving.

> **Note.** The Doppler Effect only tells us about the component of motion in our direction. If an object is moving perpendicular to the displacement vector to us, we detect no speed.

- Blueshift (shorter wavelength): motion towards you
- Redshift (longer wavelength): motion away from you
- Greater shift means greater speed

The luminosity (energy per second) passing through a given angular area is the same, regardless of how far away you are. Knowing this, and that the surface area of a sphere is $4\pi r^2$, we can see that the luminosity of an object is inversely proportional to square of the distance to the object.

> **Example.** *Light on Mars*
> Since Mars orbits around 1.5 AU away from the Sun, it gets around
> $$\left(\frac{1}{1.5}\right)^2 \approx 0.44$$
> the amount of light that the Earth gets.

## 5.3 Telescopes

- Telescopes collect more light than our eyes because they are bigger—more area to collect light.
- They can see more detail than our eyes because they provide magnification: angular resolution.
  The smallest detail you can see scales linearly with $\frac{\lambda}{D}$.
- A larger lens or shorter wavelength would allow for higher resolution.

The way that most telescopes work is either through refracting lenses or reflecting mirrors. Most research telescopes today use the latter. We put telescopes in space because that bypasses the absorption/distortion of light by Earth's atmosphere, and light pollution.
Interferometry allows two or more telescopes spread out over a large area to work together to obtain the angular resolution of a larger telescope (works well for radio astronomy).