SS1 FIRST TERM PHYSICS NOTE 2024/2025 SESSION

TOPICS

- **Introduction to Physics**
- **Fundamental and derived quantities and units**
- **Measurement of physical quantities**
- **Position, distance, displacement and rectilinear acceleration**
- **Motion**
- **Work, energy and power**
- **Mechanical energy**

AN INTRODUCTION TO PHYSICS

What is your first reaction when you hear the word "physics"? Did you imagine working through difficult equations or memorizing formulas that seem?

To have no real use in life outside the physics classroom? Many people come to the subject of physics with a bit of fear. But as you begin your exploration of this broad-ranging subject, you may soon come to realize that physics plays a much larger role in your life than you first thought, no matter your life goals or career choice.

For example, take a look at the image above. This image is of the Andromeda Galaxy, which contains billions of individual stars, huge clouds of gas, and dust. Two smaller galaxies are also visible as bright blue spots in the background. At a staggering 2.5 million light years from the Earth, this galaxy is the nearest one to our own galaxy (which is called the Milky Way). The stars and planets that make up Andromeda might seem to be the furthest thing from most people's regular, everyday lives. But Andromeda is a great starting point to think about the forces that hold together the universe. The forces that cause Andromeda to act as it does are the same forces we contend with here on Earth, whether we are planning to send a rocket into space or simply raise the walls for a new home. The same gravity that causes the stars of Andromeda to rotate and revolve also causes water to flow over hydroelectric dams here on Earth. Tonight, take a moment to look up at the stars. The forces out there are the same as the ones here on Earth. Through a study of physics, you may gain a greater understanding of the interconnectedness of everything we can see and know in this universe.

Think now about all of the technological devices that you use on a regular basis. Computers, smart phones, GPS systems, MP3 players, and satellite radio might come to mind. Next, think about the most exciting modern technologies that you have heard about in the news, such as trains that levitate above tracks, "invisibility cloaks" that bend light around them, and microscopic robots that fight cancer cells in our bodies. All of these groundbreaking advancements, commonplace or unbelievable, rely on the principles of physics. Aside from playing a significant role in technology, professionals such as engineers, pilots, physicians, physical therapists, electricians, and computer programmers apply physics concepts in their daily work. For example, a pilot must understand how wind forces affect a flight path and a physical therapist must understand how the muscles in the body experience forces as they move and bend. As you will learn in this text, physics principles are propelling new, exciting technologies, and these principles are applied in a wide range of careers.

In this text, you will begin to explore the history of the formal study of physics, beginning with natural philosophy and the ancient Greeks, and leading up through a review of Sir Isaac Newton and the laws of physics that bear his name. You will also be introduced to the standards scientists use when they study physical quantities and the interrelated system of measurements most of the scientific community uses to communicate in a single.

Physics: An Introduction

The flight formations of migratory birds such as Canada geese are governed by the laws of physics.

The physical universe is enormously complex in its detail. Every day, each of us observes a great variety of objects and phenomena. Over the centuries, the curiosity of the human race has led us collectively to explore and catalog a tremendous wealth of information. From the flight of birds to the colors of flowers, from lightning to gravity, from quarks to clusters of galaxies, from the flow of time to the mystery of the creation of the universe, we have asked questions and assembled huge arrays of facts. In the face of all these details, we have discovered that a surprisingly small and unified set of physical laws can explain what we observe. As humans, we make generalizations and seek order. We have found that nature is remarkably cooperative—it exhibits the *underlying order and simplicity* we so value.

It is the underlying order of nature that makes science in general, and physics in particular, so enjoyable to study. For example, what do a bag of chips and a car battery have in common? Both contain energy that can be converted to other forms. The law of conservation of energy (which says that energy can change form but is never lost) ties together such topics as food calories, batteries, heat, light, and watch springs. Understanding this law makes it easier to learn about the various forms energy takes and how they relate to one another. Apparently unrelated topics are connected through broadly applicable physical laws, permitting an understanding beyond just the memorization of lists of facts.

The unifying aspect of physical laws and the basic simplicity of nature form the underlying themes of this text. In learning to apply these laws, you will, of course, study the most important topics in physics. More importantly, you will gain analytical abilities that will enable you to apply these laws far beyond the scope of what can be included in a single book. These analytical skills will help you to excel academically, and they will also help you to think critically in any professional career you choose to pursue. This module discusses the realm of physics (to define what physics is), some applications of physics (to illustrate its relevance to other disciplines), and more precisely what constitutes a physical law (to illuminate the importance of experimentation to theory).

Science and the Realm of Physics

Science consists of the theories and laws that are the general truths of nature as well as the body of knowledge they encompass. Scientists are continually trying to expand this body of knowledge and to perfect the expression of the laws that describe it. **Physics** is concerned with describing the interactions of energy, matter, space, and time, and it is especially interested in what fundamental mechanisms underlie every phenomenon. The concern for describing the basic phenomena in nature essentially defines the *realm of physics*.

Physics aims to describe the function of everything around us, from the movement of tiny charged particles to the motion of people, cars, and spaceships. In fact, almost everything around you can be described quite accurately by the laws of physics.

Consider a smart phone, Physics describes how electricity interacts with the various circuits inside the device. This knowledge helps engineers select the appropriate materials and circuit layout when building the smart phone. Next, consider a GPS system. Physics describes the relationship between the speeds of an object, the distance over which it travels, and the time it takes to travel that distance. When you use a GPS device in a vehicle, it utilizes these physics
Equations to determine the travel time from one location to another.

INTRODUCTION: THE NATURE OF SCIENCE AND PHYSICS

You need not be a scientist to use physics. On the contrary, knowledge of physics is useful in everyday situations as well as in nonscientific professions. It can help you understand how microwave ovens work, why metals should not be put into them, and why they might affect pacemakers.

Physics allows you to understand the hazards of radiation and rationally evaluate these hazards more easily.

Physics also explains the reason why a black car radiator helps remove heat in a car engine, and it explains why a white roof helps keep the inside of a house cool. Similarly, the operation of a car's ignition system as well as the transmission of electrical signals through our body's nervous system are much easier to understand when you think about them in terms of basic physics.

Physics is the foundation of many important disciplines and contributes directly to others. Chemistry, for example—since it deals with the interactions of atoms and molecules—is rooted in atomic and molecular physics. Most branches of engineering are applied physics. In architecture, physics is at the heart of structural stability, and is involved in the acoustics, heating, lighting, and cooling of buildings. Parts of geology rely heavily on physics, such as radioactive dating of rocks, earthquake analysis, and heat transfer in the Earth. Some disciplines, such as biophysics and geophysics, are hybrids of physics and other disciplines.

Physics has many applications in the biological sciences. On the microscopic level (small scale), it helps describe the properties of cell walls and cell membranes

On the macroscopic level (large scale), it can explain the heat, work, and power associated with the human body. Physics is involved in medical diagnostics, such as x-rays, magnetic resonance imaging (MRI), and ultrasonic blood flow measurements. Medical therapy sometimes directly involves physics; for example, cancer radiotherapy uses ionizing radiation. Physics can also explain sensory phenomena, such as how musical instruments make sound, how the eye detects color, and how lasers can transmit information.

It is not necessary to formally study all applications of physics. What is most useful is knowledge of the basic laws of physics and a skill in the analytical methods for applying them. The study of physics also can improve your problem-solving skills. Furthermore, physics has retained the most basic aspects of science, so it is used by all of the sciences, and the study of physics makes other sciences easier to understand.

Models, Theories, and Laws; the Role of Experimentation

The laws of nature are concise descriptions of the universe around us; they are human statements of the underlying laws or rules that all natural processes follow. Such laws are intrinsic to the universe; humans did not create them and so cannot change them. We can only discover and understand them. Their discovery is a very human endeavor, with all the elements of mystery, imagination, struggle, triumph, and disappointment inherent in any creative effort. The cornerstone of discovering natural laws is observation; science must describe the universe as it is, not as we may imagine it to be.

We all are curious to some extent. We look around, make generalizations, and try to understand what we see—for example, we look up and wonder whether one type of cloud signals an oncoming storm. As we become serious about exploring nature, we become more organized and formal in collecting and analyzing data. We attempt greater precision, perform controlled experiments (if we can), and write down ideas about how the data may be organized and unified. We then formulate models, theories, and laws based on the data we have collected and analyzed to generalize and communicate the results of these experiments.

A **model** is a representation of something that is often too difficult (or impossible) to display directly. While a model is justified with experimental proof, it is only accurate under limited situations. An example is the planetary model of the atom in which electrons are pictured as orbiting the nucleus, analogous to the way planets orbit the Sun. We cannot observe electron orbits directly, but the mental image helps explain the observations we can make, such as the emission of light from hot gases (atomic spectra). Physicists use models for a variety of purposes. For example, models can help physicists analyze a scenario and perform a calculation, or they can be used to represent a situation in the form of a computer simulation. A **theory** is an explanation for patterns in nature that is supported by scientific evidence and verified multiple times by various groups of researchers. Some theories include models to help visualize phenomena, whereas others do not. Newton’s theory of gravity, for example, does not require a model or mental image, because we can observe the objects directly with our own senses. The kinetic theory of gases, on the other hand, is a model in which a gas is viewed as being composed of atoms and molecules. Atoms and molecules are too small to be observed directly with our senses—thus, we picture them mentally to understand what our instruments tell us about the behavior of gases.

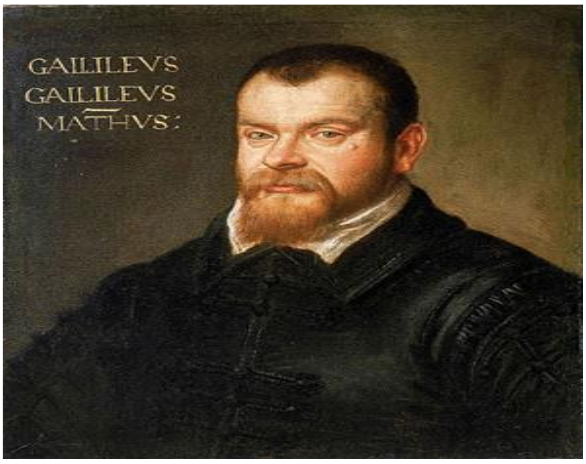
A **law** uses concise language to describe a generalized pattern in nature that is supported by scientific evidence and repeated experiments. Often, a law can be expressed in the form of a single mathematical equation. Laws and theories are similar in that they are both scientific statements that result from a tested hypothesis and are supported by scientific evidence. However, the designation *law* is reserved for a concise and very general statement that describes phenomena in nature, such as the law that energy is conserved during any process, or Newton’s second law of motion, which relates force, mass, and acceleration by the simple equation $\mathbf{F} = m\mathbf{a}$. A theory, in contrast, is a less concise statement of observed phenomena. For example, the Theory of Evolution and the Theory of Relativity cannot be expressed concisely enough to be considered a law. The biggest difference between a law and a theory is that a theory is much more complex and dynamic. A law describes a single action, whereas a theory explains an entire group of related phenomena. And, whereas a law is a postulate that forms the foundation of the scientific method, a theory is the end result of that process.

Less broadly applicable statements are usually called principles (such as Pascal’s principle, which is applicable only in fluids), but the distinction between laws and principles often is not carefully made.

The Evolution of Natural Philosophy into Modern Physics

Physics was not always a separate and distinct discipline. It remains connected to other sciences to this day. The word *physics* comes from Greek, meaning nature. The study of nature came to be called “natural philosophy.” From ancient times through the Renaissance, natural philosophy encompassed many fields, including astronomy, biology, chemistry, physics, mathematics, and medicine. Over the last few centuries, the growth of knowledge has resulted in ever-increasing specialization and branching of natural philosophy into separate fields, with physics retaining the most basic facets. Physics as it developed from the Renaissance to the end of the 19th century is called **classical physics**. It was transformed into modern physics by revolutionary discoveries made starting at the beginning of the 20th century.

Over the centuries, natural philosophy has evolved into more specialized disciplines, as illustrated by the contributions of some of the greatest minds in history.



Galileo Galilei (1564–1642) laid the foundation of modern experimentation and made contributions in mathematics, physics, and astronomy.

Niels Bohr (1885–1962) made fundamental contributions to the development of quantum mechanics, one part of modern physics.

Classical physics is not an exact description of the universe, but it is an excellent approximation under the following conditions: Matter must be moving at speeds less than about 1% of the speed of light, the objects dealt with must be large enough to be seen with a microscope, and only weak gravitational fields, such as the field generated by the Earth, can be involved. Because humans live under such circumstances, classical physics

Seems intuitively reasonable, while many aspects of modern physics seem bizarre. This is why models are so useful in modern physics—they let us conceptualize phenomena we do not ordinarily experience. We can relate to models in human terms and visualize what happens when objects move at high speeds or imagine what objects too small to observe with our senses might be like. For example, we can understand an atom's properties because we can picture it in our minds, although we have never seen an atom with our eyes. New tools, of course, allow us to better picture phenomena we cannot see. In fact, new instrumentation has allowed us in recent years to actually "picture" the atom.

Limits on the Laws of Classical Physics

For the laws of classical physics to apply, the following criteria must be met: Matter must be moving at speeds less than about 1% of the speed of light, the objects dealt with must be large enough to be seen with a microscope, and only weak gravitational fields (such as the field generated by the Earth) can be involved.

Some of the most spectacular advances in science have been made in modern physics. Many of the laws of classical physics have been modified or rejected, and revolutionary changes in technology, society, and our view of the universe have resulted. Like science fiction, modern physics is filled with fascinating objects beyond our normal experiences, but it has the advantage over science fiction of being very real. Why, then, is the majority of this text devoted to topics of classical physics? There are two main reasons: Classical physics gives an extremely accurate description of the universe under a wide range of everyday circumstances, and knowledge of classical physics is necessary to understand modern physics.

Modern physics itself consists of the two revolutionary theories, relativity and quantum mechanics. These theories deal with the very fast and the very small, respectively. **Relativity** must be used whenever an object is traveling at greater than about 1% of the speed of light or experiences a strong gravitational field such as that near the Sun. **Quantum mechanics** must be used for objects smaller than can be seen with a microscope. The combination of these two theories is *relativistic quantum mechanics*, and it describes the behavior of small objects traveling at high speeds or experiencing a strong gravitational field. Relativistic quantum mechanics is the best universally applicable theory we have. Because of its mathematical complexity, it is used only when necessary, and the other theories are used whenever they will produce sufficiently accurate results. We will find, however, that we can do a great deal of modern physics with the algebra and trigonometry used in this text.

What Is Physics?

1. Physics is the scientific study of matter and energy and how they interact with each other, grouped in traditional fields such as acoustics, optics, and mechanics.
   This energy can take the form of motion, light, electricity, radiation, gravity etc. Physics deals with matter on scales ranging from sub-atomic particles (i.e. the particles that make up the atom and the particles that make up *those* particles) to stars and even entire galaxies.

2. It is physical processes and phenomena of a particular system, that is, the physical properties and component of something.

General Objectives of Physics Curriculum:
Physics is crucial for effective living in the modern age of science and technology, Given its application in industry and many other professions, it is necessary that students are given opportunity to acquire some of its concepts, principles and skills.

Basic Physics Concepts
Physics is a systematic study of the natural world, a discipline that attempts to quantify reality through a precise application of observation coupled with logic and reason. In order to make use of such a discipline, of course, there is certain foundational information that you must have first, in order to build upon it

The Five Most Important Concepts in Physics

A. Energy will dissipate from an area of higher energy to one of lower energy without the input of additional energy.

This law governs all energy flow, especially observable in the cases of thermal and electrical energy flow. Heat moves from the hot tea to the relatively cold mug and surrounding air. Electrons tend to spread until an even charge is obtained throughout the entire system. This can also be directly observed with a drop of dye added to a glass of water. The colour will dissipate until the entire solution is a uniform colour.

B. Newton's Three Laws of Motion

1st Law: A body in rest tends to stay at rest, and a body in motion tends to stay in motion, unless the body is compelled to change its state. The evidence supporting the first part of this statement is easily seen. We know that a wheel will not begin rolling by itself. However, we do not see the proof of the second half in our world. That is because there is an ever present inhibiting force known as friction that acts as the external force resisting perpetual motion.

2nd Law: The time rate of change of momentum of a body is directly proportional to applied force acting on it and takes place in the direction of the force.

$F\alpha \frac{Mv}{t}$ Where Ft = Impulse, Mv = Linear Momentum

$Ft = Mv$

$F = \frac{Mv}{t} = ma \qquad a = \frac{F}{m}$

The acceleration of a body is dependent upon both the mass of the object (not its *weight*) and the net force perpetuating the motion (total force in the direction of the motion minus the force resisting motion). In the formula, a resisting force would be written as negative to produce a negative acceleration, which means the object would be slowing down.

3rd Law: For every action there is an equal and opposite reaction. This means that if I push you, I myself will be slightly pushed back in the process. This is the principle at work behind how jet planes and rockets propel themselves. They expel gases in the opposite direction, are pushed themselves in the process, and thus move forward.

C. The Laws of the Conservation of Energy and of Mass

These laws are intimately intertwined and state that, under normal conditions, the total energy of a contained system and the total mass of that contained system will remain constant. It also postulates that neither mass nor energy can be created nor destroyed, that they merely change form (e.g. energy---electrical changes to thermal, or mass--- liquid changes to gas). Fairly recently, though under laboratory conditions, scientists have actually observed a minute loss of total mass in a closed system, and this has been attributed to the fact that the mass had actually changed into energy. This led to a modification of the laws, which made the provision that mass and energy can actually change into each other.

D. Wave-Particle Duality

The principle of quantum mechanics which implies that light (and, indeed, all other subatomic particles) sometimes act like a wave, and sometimes act like a particle, depending on the experiment you are performing. For instance, low frequency electromagnetic radiation tends to act more like a wave than a particle; high frequency electromagnetic radiation tends to act more like a particle than a wave.

E. The Four Fundamental Forces of Nature

Strong- This force is a nuclear force. Its purpose is to hold the nucleus of an atom together, but it decays rapidly with distance; it doesn't even extend beyond an atom's nucleus!!

Weak- The weak nuclear force is associated with beta decay. It is responsible for the nuclear breakdown of neutrons into protons and electrons.

Gravitational- The weakest of the four forces, but still holds us to the Earth, keeps our planet in orbit around the sun, and causes the tides to rise and fall.

Electromagnetic-This force is used on the atomic level to hold the atom together. It is caused by the opposing charges of electrons and protons

What are the various branches of physics?

Physics is the most fundamental of all sciences and therefore, branches of physics have evolved to understand every underlying aspect of the physical world.

Physics can be divided into two main branches: mechanics (the study of the behavior of forces and objects acting due to those forces); and, electricity and magnetism (which delves into the science of the atom).

The fundamental branches of physics:
classical mechanics
electromagnetism (including optics)
relativity
thermodynamics
quantum mechanics
astronomy
Some of the more popular or modern branches of physics:
Astro and space physics (study of stars, planets, black holes, etc.)
geophysics (study of like earthquakes and plate tectonics)
nuclear physics
particle physics
medical physics
biophysics, and quantum physics, which is mostly theoretical

What is the Fields or Disciplines of Physics?

Physics is a diverse area of study and in order to make sense of it scientists have been forced to focus their attention on one or two smaller areas of the discipline. This allows them to become experts in that narrow field, without getting bogged down in the sheer volume of knowledge that exists regarding the natural world.

Below is a list - by no comprehensive - of different disciplines of physics.

- **Acoustics** - the study of sound & sound waves
- **Astronomy** - the study of space
- **Astrophysics** - the study of the physical properties of objects in space
- **Atomic Physics** - the study of atoms, specifically the electron properties of the atom
- **Biophysics** - the study of physics in living systems
- **Chaos** - the study of systems with strong sensitivity to initial conditions, so a slight change at the beginning quickly become major changes in the system
- **Chemical Physics** - the study of physics in chemical systems
- **Computational Physics** - the application of numerical methods to solve physical problems for which a quantitative theory already exists
- **Cosmology** - the study of the universe as a whole, including its origins and evolution
- **Cryophysics / Cryogenics / Low Temperature Physics** - the study of physical properties in low temperature situations, far below the freezing point of water
- **Crystallography** - the study of crystals and crystalline structures
- **Electromagnetism** - the study of electrical and magnetic fields, which are two aspects of the same phenomenon
- **Electronics** - the study of the flow of electrons, generally in a circuit
- **Fluid Dynamics / Fluid Mechanics** - the study of the physical properties of "fluids," specifically defined in this case to be liquids and gases
- **Geophysics** - the study of the physical properties of the Earth
- **High Energy Physics** - the study of physics in extremely high energy systems, generally within particle physics
- **High Pressure Physics** - the study of physics in extremely high pressure systems, generally related to fluid dynamics
- **Laser Physics** - the study of the physical properties of lasers

- **Mathematical Physics** - applying mathematically rigorous methods to solving problems within physics
- **Mechanics** - the study of the motion of bodies in a frame of reference
- **Meteorology / Weather Physics** - the physics of the weather
- **Molecular Physics** - the study of physical properties of molecules
- **Nanotechnology** - the science of building circuits and machines from single molecules and atoms
- **Nuclear Physics** - the study of the physical properties of the atomic nucleus
- **Optics / Light Physics** - the study of the physical properties of light
- **Particle Physics** - the study of fundamental particles and the forces of their interaction
- **Plasma Physics** - the study of matter in the plasma phase
- **Quantum Electrodynamics** - the study of how electrons and photons interact at the quantum mechanical level
- **Quantum Mechanics / Quantum Physics** - the study of science where the smallest discrete values, or quanta, of matter and energy become relevant
- **Quantum Optics** - the application of quantum physics to light
- **Quantum Field Theory** - the application of quantum physics to fields, including the fundamental forces of the universe
- **Quantum Gravity** - the application of quantum physics to gravity and unification of gravity with the other fundamental particle interactions
- **Relativity** - the study of systems displaying the properties of Einstein's theory of relativity, which generally involves moving at speeds very close to the speed of light
- **Statistical Mechanics** - the study of large systems by statistically expanding the knowledge of smaller systems
- **String Theory / Superstring Theory** - the study of the theory that all fundamental particles are vibrations of one-dimensional strings of energy, in a higher-dimensional universe
- **Thermodynamics** - the physics of heat

It should become obvious that there is some overlap. For example, the difference between astronomy, astrophysics, and cosmology can be virtually meaningless at times to everyone that is, except the astronomers, astrophysicists, and cosmologists, who can take the distinctions very seriously.

Assignment:

1. What is physics? Give me key terms in the definition of physics.
2. List FIVE objectives of physics curriculum
3. Explain in one page what you understand by the concept of physics
4. List **Four** fundamental forces in nature
5. State **three** Newton’s Laws of Motion
6. Differentiate between strong force and Electromagnetic force
7. List **five** branches of physics
8. Explain **Two** the of the branches of physics
9. List **Four** disciplines in physics
10. Explain **Three** of the physics discipline mentioned
11. Write short note on one discipline in physics of your choice.

LESSON 2 NOTE

FUNDAMENTALS AND DERIVED QUANTITIES, UNITS AND DIMENSION ANALYSIS

PHYSICAL QUANTITY

A physical quantity is a physical property of a phenomenon, body, or substance that can be quantified by measurement. Example**:**

> If the temperature T of a body is quantified as 300 Kelvin (in which T is the quantity symbol, 300 the value, and K is the unit), this is written
> $T = 300 \times K = 300$ K,

There are different instruments used by physicists for measuring physical quantities and different units in which these quantities are expressed. There are also relationships between quantities and some uncertainties associated with the measuring device

FUNDAMENTAL QUANTITIES

Fundamental quantities are the basic quantities that are independent of others and cannot be defined in terms of other quantities or derived from them. They are the basic quantities upon which most (though not all) quantities depend.
There are three most important quantities in physics namely: length, mass and time

Length may be defined as the extent of space or distance extended.
Mass is commonly defined as the quantity of matter or material substance.
Time is defined as that in which events are distinguishable with reference to before or after

DERIVED QUANTITY

The physical quantities which can be derived from other physical quantities are called **derived quantities.** All other quantities except the fundament quantities are derivable. The unit of these quantities are also derived from the fundamental unit and are called derived units. Examples: energy (work), force, capacitance, charge resistance etc.

In theory, a system of fundamental quantities (or sometimes fundamental dimensions) would be such that every other physical quantity (or dimension of physical quantity) can be generated from them. One could eliminate any two of the metre, kilogram and second by setting c and h to unity or to a fixed dimensionless number.

UNIT OF MEASUREMENT

A unit of measurement is a definite magnitude of a physical quantity, defined and adopted by convention and/or by law, that is used as a standard for measurement of the same physical quantity. Any other value of the physical quantity can be expressed as a simple multiple of the unit of measurement.

FUNDAMENTAL UNITS:

A set of **fundamental units** is a set of units for physical quantities from which every other unit can be generated or are the basic unit upon which other units depends. They are the unit of the fundamental quantities.

For example, length is a physical quantity. The metre is a unit of length that represents a definite predetermined length. When we say 10 metres (or 10 m), we actually mean 10 times the definite predetermined length called "metre". The definition, agreement, and practical use of units of measurement have played a crucial role in human endeavour from early ages up to this day. Different systems of units used to be very common. Now there is a global standard, the International System of Units (SI), the modern form of the metric system. In the SI system, there are seven fundamental units: kilogram, meter, candela, second, ampere, kelvin, and mole. Examples of fundamental quantities and their units are as in Table below:

Fundamental Quantities and units

Quantity	Unit	Unit abbreviation
Length	Metre	m
Time	Second	s
Mass	Kilogram	kg
Electric Current	Ampere	A
Temperature	Kelvin	K
Amount of Substance	mole	mol
Luminous intensity	Candela	cd

A unit or standard measurement should be such that:

(a) It must be possible to define it unambiguously.
(b) It is easily reproducible
(c) It does not vary with time and place
(d) It should be possible to multiply or divide each one the standard

INTERNATIONAL SYSTEM OF UNITS

The International System of Units (abbreviated as SI from the French language name *Système International d'Unités*) is the modern revision of the metric system. It is the world's most widely used system of units, both in everyday commerce and in science. The SI was developed in 1960 from the metre-kilogram-second (MKS) system, rather than the centimetre-gram-second (CGS) system, which, in turn, had many variants. At its development the SI also introduced several newly named units that were previously not a part of the metric system. The SI units for the four basic physical quantities: length, time, mass, and temperature are:

- metre (m) :SI unit of length
- second (s) :SI unit of time
- kilogram (kg) :SI unit of mass
- kelvin (K) :SI unit of temperature

There are two types of SI units, base units and derived units. Base units are the simple measurements for time, length, mass, temperature, amount of substance, electric current and light intensity. Derived units are constructed from the base units, for example, the watt, i.e. the unit for power, is defined from the base units as $m^2 \cdot kg \cdot s^{-3}$. Other physical properties may be measured in compound units, such as material density, measured in kg/m^3.

DERIVED UNITS:

The units of physical quantities which can be expressed in terms of fundamental unit are called derived unit. For example , area, pressure, density and speed are derived quantities and their unit – square meter, Paschal kilogram metre -^{3} and derived from the fundamental unit

Derived Quantities and units

Quantity	Unit	Unit abbreviation
Capacitance	Farad	F Coulomb/volt, (amp x second/volt)

Charge	Coulomb	C (amp x second)
Energy (work)	Joule	J (N/m) Kg x m^2/sec^2
Force	Newton	N (Newton-metre) (Joules/metre), kg x m/sec^2
Inductance	Henry	H (volt x sec/amp)
Magnetic flux density	Tesla	T (webers/$metre^2$), (Joules x second), (Coulomb x $metre^2$)
Potential difference (electromotive force)	Volt	V (Joules/ Coulomb), (kg x m^2/(sec2 x coulomb)), watts/ Ampere
Power	Watt	W (Joules/second), (volts x ampere)
Resistance	Ohm	Ω

UNITS OF MEASUREMENT IN INDUSTRY

The units in industry and business sometimes differs from those used in the laboratory, because, in these areas the quantity involved are very large. For example;

1. Power measured in watts in the laboratory may be measured in Horse power in the industry. One horsepower (1hp) equal 0.746 kilowatt
2. In the laboratory, oil is measured in litres while in oil industries, the barrel is used as the unit of measurement; I barrel is between 159 to 120 litres of oil. Oil prices are usually quoted in dollars per barrel.
3. A square metre is the unit of measurement of an area of a land in the laboratory but in industry, areas of land are measured in acres or hectare. An hectare (h) is equivalent to 10,000 square metre.
4. The thermometric scale of temperature in the laboratory is in degree Celsius ^{0}C or Kelvin K but in the industry temperature is measured in ^{0}F. 0^0C <=> 273K < => 32 ^{0}F

°F, the **Fahrenheit Scale** (used in the US), and **°C**, the **Celsius Scale** (part of the Metric System, used in most other countries)

They both measure the same thing (temperature!), just using different numbers. If you freeze water, it measures 0° in Celsius, but 32° in Fahrenheit, If you boil water, it measures 100° in Celsius, but 212° in Fahrenheit

The difference between freezing and boiling is 100° in Celsius, but 180° in Fahrenheit.

Conversion Method

There are two ways we could convert from one temperature scale to another, they are:

i. Formula method
ii. Interpolation method

i. Formula Method

The formula for conversion can be written as follows:

Celsius to Fahrenheit: $\left(°C \times \frac{9}{5}\right) + 32 = °F$

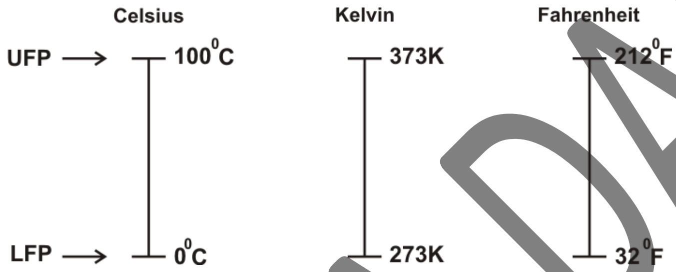
Fahrenheit to Celsius: $(°F - 32) \times \frac{5}{9} = °C$
Celsius to Kelvin: $°C + 273 = K$
Kelvin to Celsius: $K - 273 = °C$

ii. Interpolation Method

For this method to be used, the upper and lower fixed points of each scale of temperature must be known.

Upper fixed point is the temperature of pure boiling water at standard atmospheric pressure.
Lower fixed point is the temperature of pure melting ice at standard atmospheric pressure.

The diagram below shows the upper and lower fixed points of the three temperature scales:



Examples (copy from the board)

Typical Temperatures

^{0}C	^{0}F	Description
100	212	Water boils
40	104	Hot bath
37	98.6	Body temperature
30	86	Beach weather
21	70	Room temperature
10	50	Cool day
-18	0	Very cold day
0	32	Freezing
-40	40	Extremely cold day

DIMENSIONAL ANALYSIS

In physics and all science, **dimensional analysis** is a tool to find or check relations among physical quantities by using their dimensions. The dimension of a physical quantity is the combination of the basic physical dimensions (usually mass, length, time, electric charge, and temperature) which describe it; for example, speed has the dimension length per unit time, and may be measured in meters per second, miles per hour, or other units. Dimensional analysis is based on the fact that a physical law must be independent of the units used to measure the physical variables. A straightforward practical consequence is that any meaningful equation (and any inequality in equation) must have the same dimensions in the left and right sides. Checking this is the basic way of performing dimensional analysis.

Definition

The dimensions of a physical quantity are associated with combinations of mass, length, time, electric charge, and temperature, represented by sans-serif symbols **M**, **L**, **T**, **Q**, and **Θ**, respectively, each raised to rational powers.

S/N	Physical Quantity	Formula	Unit	Dimension
1	Force	mass × acceleration or "mass×(distance/time)/time"	Newton	$\mathbf{ML/T^2}$ or $\mathbf{MLT^{-2}}$
2	Velocity or speed	*distance/time*	metre/s	$\mathbf{L/T}$ or $\mathbf{LT^{-1}}$
3	Acceleration	velocity/time or (distance/time)/time		$\mathbf{LT^{-2}}$
4	Energy or Work	Force × distance or "(mass×(distance/time)/time) × distance"	Joules	$\mathbf{M\,L^2T^{-2}}$
5	Power	energy/time or "((mass×(distance/time)/time) × distance)/time"	Watt Or Joules/s	$\mathbf{M\,L^2T^{-3}}$

USES OF DIMENSIONAL ANALYSIS

1. Dimensional analysis is routinely used to check the plausibility of derived equations and computations.
2. It is also used to form reasonable hypotheses about complex physical situations that can be tested by experiment or by more developed theories of the phenomena,
3. And to categorize types of physical quantities and units based on their relations to or dependence on other units, or their dimensions if any.

Example1:

Suppose a bob is hanging from a ceiling and the period of oscillations, T, depends on length, l, of the thread, mass, m, of the bob and acceleration due to gravity, g. Where T is in seconds and l in metres. Derive a relationship between T, l, m and g.

Solution

$T \propto l^x m^y g^z$

$T = kl^x m^y g^z$
$M^0 L^0 T^1 = kL^x M^y [LT^{-2}]^z$
$M^0 L^0 T^1 = kL^{x+Z} M^y T^{-2Z}$
By comparing powers,
$x + z = 0,$
$y = 0,$
$-2z = 1$
By solving the equation, we get
$x = \frac{1}{2}$, $y = 0$ and $z = -\frac{1}{2}$
Therefore,
$T = kl^{1/2} m^0 g^{-1/2}$
Therefore,

$$T = k\sqrt{\frac{l}{g}}$$

Example2: Check whether the equation given below is dimensionally correct.

$W = \frac{1}{2}mv^2 - mgh$, where W is workdone, m is mass, h is height, v is velocity and g is acceleration due to gravity.

Solution

$$W = \frac{1}{2}mv^2 - mgh$$

(LHS) (RHS)
Let us divide the equation into two sides, LHS and RHS

For LHS,
$W = F \times d = m \times a \times d$
$W = kg \times \frac{m}{s^2} \times m = kgm^2 s^{-2} = ML^2T^{-2}$

For RHS
$\frac{1}{2}mv^2 = kg \times \left(\frac{m}{s}\right)^2 = kgm^2 s^{-2} = ML^2T^{-2}$;
$mgh = kg \times \frac{m}{s^2} \times m = kgm^2 s^{-2} = ML^2T^{-2}$
So the dimensions of LHS and RHS are same, therefore, the equation is dimensionally correct.

Assignment:
1. Define physical quantities with examples
2. Differentiate between fundamental and derived quantities
4. What is the difference between fundamental and derived units?
5. List THREE basic fundamental and TWO derived quantities
6. Differentiate between fundamental and derived quantities.
7. List THREE units of measurement in industry
8. Give their equivalent I SI units
9. List THREE thermometric units
10. State the conversion formula from Celsius to Fahrenheit
11. The electrical metre of St. Leo hostel reads 2.984kw. Convert to horse power (hp)
12. How many barrels of oils are there in $2x10^5$ litres of oil?
13. Convert 2,000 hectare of land into square metre

14. Define dimension of a physical quantity
15. List THREE uses of dimensional analysis
16. Give the mathematical properties of dimension of basic physical quantities
17. Derive and write the dimensions of physical quantities
18. Derive and write simple dimension of m/s, m^3 and

LESSON 3 NOTE

MEASUREMENT OF PHYSICAL QUANTITIES

Measurement is a very important aspect of physics and other sciences. No fact in sciences is accepted, no law is established unless it can be exactly measured and quantified. It is basically a means of communication and is used by scientists and engineers for understanding natural phenomenon, by the society for transacting business, and by engineers for practical ends.

Measurement is the process or the result of determining the ratio of a physical quantity, such as a length or a mass, to a unit of measurement, such as the meter or the kilogram. The science of measurement is called metrology. As physics is based on exact measurements, every such measurement requires two things: first a number or quantity, and secondly a **unit, e.g**. 10 meters as the length of a room. That is, the measurement of any physical quantity involves comparison with a certain basic, arbitrarily chosen, internationally accepted reference standard called **Uni**t.

Measurement of Distance /Length: Distance /Length are measured using a string, graduated scale such as a meter rule, vernier calliper and micrometre screw gauge.

Meter rule is used in measuring the length of a table. The precision of a measurement depends on the graduation of the instrument being used. One can estimate the length to a fraction of the least graduation on the scale.

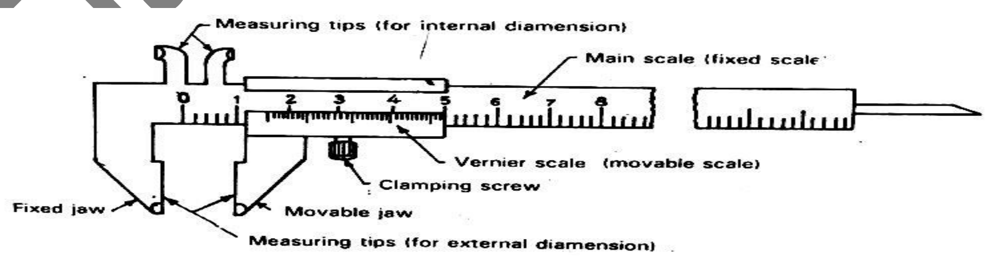
The last digit has to be estimated. Conventionally, the uncertainty (or error) in the measurement is taken to be half the smallest scale division, the uncertainty or error is 0.5mm or 0.05cm.

Vernier calliper

The Vernier caliper is an extremely precise measuring instrument; the reading error is 1/20 mm = 0.05 mm. It is used to take measurements that are accurate to within .001 of an inch or 0.01 of a millimetre, depending whether the vernier is imperial or metric. It is used to measure small internal and external distances extremely accurately.

Example include;

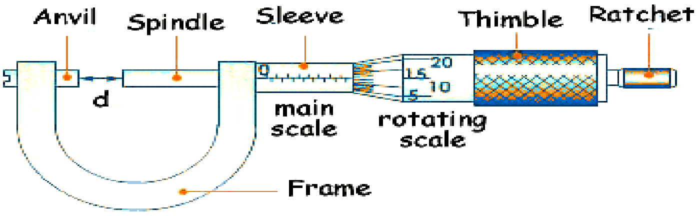
1. the diameter of a rod
2. the inside diameter of a tube.
3. the external measurement (diameter) of a round section piece of steel



On those rare occasions when the reading just happens to be a "nice" number like 2 cm, don't forget to include the zero decimal places showing the precision of the measurement and the reading error. So not 2 cm, but rather (2.000 ± 0.005) cm or (20.00 ± 0.05) mm.

Micrometre screw gauge

A micrometre screw gauge is used to measure smaller lengths e.g. diameter of a wire, diameter of a small ball (e.g. a pendulum bob) or the thickness of a piece of paper. It can have an accuracy of 0.001 cm. Micrometre screw gauge like vernier calliper has main scale and vernier scale.



The main scale is graduated in millimetres while the circular vernier scale consists of 50 equal divisions.

When the screw head carrying the circular vernier scale is turned round once, it moves a distance of 0.5 mm along the main scale. Thus one division on the vernier scale equals 0.5/50 or 0.01 mm on the last scale. The thimble passes through a frame that carries a millimetre scale graduated to 0.5 mm. The jaws can be adjusted by rotating the thimble using the small ratchet knob. This includes a friction, clutch which prevents too much tension being applied. The thimble must be rotated through two revolutions to open the jaws by 1 mm.

Concept of Time and measurement of time

Time is one of the seven fundamental physical quantities in the International System of Units. Time is used to define other quantities — such as velocity — so defining time in terms of such quantities would result in circularity of definition. Time is a part of the measuring system used to sequence events, to compare the durations of events and the intervals between them, and to quantify rates of change such as the motions of objects. The temporal position of events with respect to the transitory present is continually changing; future events become present, and then pass further and further into the past. Time has been a major subject of religion, philosophy, and science, but defining it in a non-controversial manner applicable to all fields of study has consistently eluded the greatest scholars.

Definition of Time

A simple definition of time states that "time is what clocks measure"

An operational definition of time, wherein one says that observing a certain number of repetitions of one or another standard cyclical event (such as the passage of a free-swinging pendulum) constitutes one standard unit such as the second, is highly useful in the conduct of both advanced experiments and everyday affairs of life.

A chronometer is a portable timekeeper that meets certain precision standards. Initially, the term was used to refer to the marine chronometer, a timepiece used to determine longitude by means of celestial navigation, a precision firstly achieved by John Harrison. More recently, the term has also been applied to the chronometer watch, a wristwatch that meets precision standards set by the Swiss agency COSC.

Temporal measurement, or chronometry, takes two distinct period forms: the calendar, a mathematical abstraction for calculating extensive periods of time, and the clock, a physical mechanism that counts the on-going passage of time. In day-to-day life, the clock is consulted for periods less than a day, the calendar, for periods longer than a day. Increasingly, personal electronic devices display both calendars and clocks simultaneously. The number (as on a clock dial or calendar) that marks the occurrence of a specified event as to hour or date is obtained by counting from a fiducially epoch - a central reference point.

Calendar as a Measurement of time

Artefacts from the Palaeolithic suggest that the moon was used to calculate time as early as 6,000 years ago. Lunar calendars were among the first to appear, either 12 or 13 lunar months (either 354 or 384 days). Without intercalation to add days or months to some years, seasons quickly drift in a calendar based solely on twelve lunar months. Lunisolar calendars have a thirteenth month added to some years to make up for the difference between a full year (now known to be about 365.24 days) and a year of just twelve lunar months. The numbers twelve and thirteen came to feature prominently in many cultures, at least partly due to this relationship of months to years.

Time measurement devices

A large variety of devices have been invented to measure time. The study of these devices is called horology. They include: sundial, water clock or *clepsydra*, hourglass, quartz watch, Incense sticks and candles, Chip-scale atomic clocks, atomic clocks.

1. **SUNDIAL**: An Egyptian device dating to c.1500 BC, similar in shape to a bent T-square, measured the passage of time from the shadow cast by its crossbar on a nonlinear rule. The T was oriented eastward in the mornings. At noon, the device was turned around so that it could cast its shadow in the evening direction. A sundial uses a gnomon to cast a shadow on a set of markings which were calibrated to the hour. The position of the shadow marked the hour in local time.

2. **WATER CLOCK OR *CLEPSYDRA:*** The most precise timekeeping devices of the ancient world were the water clock or *clepsydra*, one of which was found in the tomb of Egyptian pharaoh Amenhotep I (1525–1504 BC). They could be used to measure the hours even at night, but required manual upkeep to replenish the flow of water. The Greeks and Chaldeans regularly maintained timekeeping records as an essential part of their astronomical observations. Arab inventors and engineers in particular made improvements on the use of water clocks up to the Middle Ages. In the 11th century, Chinese inventors and engineers invented the first mechanical clocks to be driven by an escapement mechanism.

3. THE HOURGLASS

Hourglass uses the flow of sand to measure the flow of time. They were used in navigation. Ferdinand Magellan used 18 glasses on each ship for his circumnavigation of the globe (1522). The flow of sand in an hourglass can be used to keep track of elapsed time. It also concretely represents the present as being between the past and the future.

4. A contemporary quartz watch

5. INCENSE STICKS AND CANDLES: were, and are, commonly used to measure time in temples and churches across the globe.

6. WATER CLOCKS, and later, mechanical clocks, were used to mark the events of the abbeys and monasteries of the middle Ages. Richard of Wallingford (1292–1336), abbot of St. Alban's abbey, famously built a mechanical clock as an astronomical ornery about 1330. Great advances in accurate time-keeping were made by Galileo Galilei and especially Christian Huygens with the invention of pendulum driven clocks.

7. **SHIP'S BELLS:** The passage of the hours at sea were marked by bells, and denoted the time (see ship's bells). The hours were marked by bells in the abbeys as well as at sea.

8. CHIP-SCALE ATOMIC CLOCKS

Chip-scale atomic clocks: such as this one unveiled in 2004, are expected to greatly improve GPS location. Clocks can range from watches, to more exotic varieties such as the Clock of the Long Now. They can be driven by a variety of means, including gravity, springs, and various forms of electrical power, and regulated by a variety of means such as a pendulum.

DEFINITION AND STANDARDS UNITS OF TIME

Unit	Size	Notes
yoctosecond	10^{-24} s	
zeptosecond	10^{-21} s	
attosecond	10^{-18} s	shortest time now measurable
femtosecond	10^{-15} s	pulse time on fastest lasers
picosecond	10^{-12} s	time for molecules to fluoresce
nanosecond	10^{-9} s	
microsecond	10^{-6} s	
millisecond	0.001 s	
second	**1 s**	**SI base unit**
minute	60 seconds	
hour	60 minutes	
day	24 hours	
week	7 days	Also called *sennight*
fortnight	14 days	2 weeks
lunar month	27.2–29.5 days	Various definitions of *lunar month* exist
month	28–31 days	
quarter	3 months	
year	12 months	
common year	365 days	52 weeks + 1 day
leap year	366 days	52 weeks + 2 days
tropical year	365.24219 days	Average

Gregorian year	365.2425 days	Average
Olympiad	4 year cycle	
lustrum	5 years	Also called *pentad*
decade	10 years	
Indiction	15 year cycle	
generation	17–35 years	Approximate
jubilee (Biblical)	50 years	
century	100 years	
millennium	1,000 years	

Mass

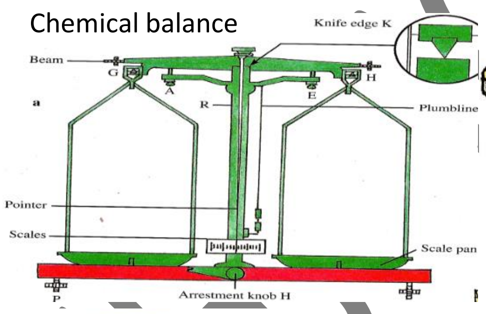
Mass is a measure of the amount of material in an object, being directly related to the number and type of atoms present in the object. Mass do not change with a body's position, movement or alteration of its shape unless material is added or removed. The mass is a fundamental property of an object, a numerical measure of its inertia and a fundamental measure of the amount of matter in the object. In the SI system the mass unit is the *kg*

Measurement of Mass

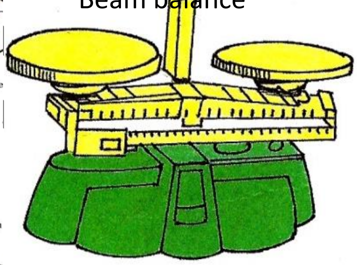
The mass of a body is measured by comparing it with standard masses. The instrument used is a balance. There are different types of balance which include;

1. A beam
2. Chemical balance
3. A lever

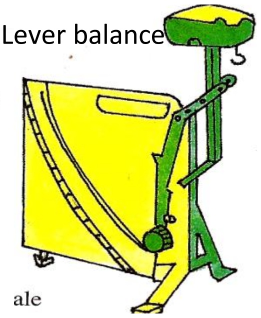
Chemical balance



Beam balance



Lever balance



Direct reading balance

A beam

A beam balance is used to measure the mass of an object. It works with the principle of moment and the reading accuracy could be up to 0.001 grams. To measure the mass of an object with a beam balance, the object is placed on the left-hand scale pan. The beam of the balance should swing freely about a pivot in the centre of the beam when the object is raised for weighing. The standard masses are then added until the pointer balances on the central mark of the scale. The masses in the two scales are said to be equal when this happens**.**

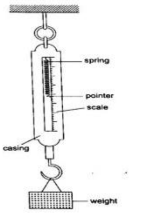
Precautions to be taken when using a Beam Balance

a. The standard masses should be picked up with a forceps not bare hand
b. Ensure that the object to be measured are dried by wiping dry
c. Do not measure hot object but allow to cool
d. Do not add or remove standard masses from the scale pan while the beam is raised

Weight

Weight is the **gravitational force** acting on a body mass. Transforming Newton's Second Law related to the weight as a $W = mg$ *where* $w = weight(N)$, $m = mass(kg)$, $g = acceleration\ due\ to\ gravity(m/s^2)$ In the SI system since the weight is a force - the weight unit is the *Newton* (*N*).

Spring balance



The weight of an object is found with a spring balance. Spring balance works on the principle of Hook's law which states that the extension of the spring of balance is proportional to the applied force provided that the elastic limit is not exceeded. The spring balance has a uniform scale and measures the weight directly. The object to be measured is suspended from the hook of the spring balance, the weight causes the spring to stretch hence moving the pointer to the graduated scale. A body with 1 kg mass can be expressed as: *w = (1 kg) (9.807 m/s²)* *= <u>9.807</u> (N)*

Where 9.807 m/s^2 = standard gravity close to earth in the SI system

As a result:

- A 9.807 N force acting on a body with 1 kg mass will give the body an acceleration of 9.807 m/s^2
- a body with mass of 1 kg weighs 9.807 N

Example - Weight versus Mass

A car's mass is *1,644 kg*. The weight can be calculated:

w = (1,644 kg)(9.807 m/s^2)
= 16122.7 N
= 16.1 kN

- there is a force (weight) of *16.1 kN* between the car and the earth.

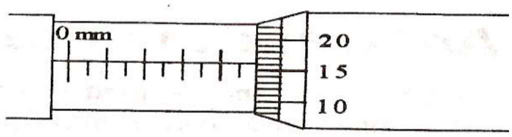
The difference between Weight and mass

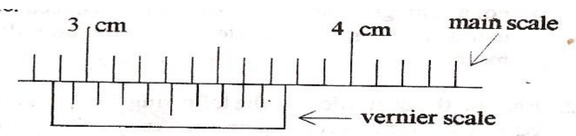
MASS	WEIGHT
S.I Unit is kilogram	S.I Unit is Newton ($kgms^{-2}$)
It is a quantity of matter in a body	It is the force which the earth attracts an object suspended above the earth's surface
It is a scalar quantity	It is a vector quantity
It is the same from place to place	It varies from place to place

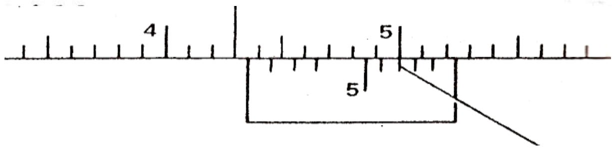
Assignment:

1. Explain the importance of measurement in physics
2. Distinguish between mass and weight
3. What are the instruments used in measuring mass and weight
4. How many seconds are there in 1 year, 2 days and 3 month of march
5. Which of the following statements about spring/chemical balance is NOT correct
   a. chemical balance operates on the principle of moment
   b. the spring balance operates on Hook's law
   c. Either may be used to measure the weight of a substance

d. The reading of a spring balance changes
6. Name the instrument used in the measurement of the length of a wire. What is the accuracy of this instrument?
7. What are the zero errors in meter rule, micrometre screw gauge and vernier Calliper
8. Give the measurement of the following instrument







LESSON 4 NOTE

POSITION, DISTANCE, DISPLACEMENT AND RECTILINEAR ACCELERATION

Concept of position as a location of point: Many of the objects we encounter in everyday life are in motion or have parts that are in motion. The physical law that governs the motion of these objects are universal, i.e. all objects move according to the same rules. To understand the motion of an object Position, distance and displacement has to be understood.

POSITION

Position is precisely where an object is located. The position of a point in space is determined by its distance and direction from other points. The statement of position of an object is always taken with respect to a frame of reference or a point of reference. The straight line motion of a particle is the easiest to describe and we begin this section with it. Straight line motion can be purely vertical (as that of a falling ball), purely horizontal (as that of a cyclist on a straight road) or slanted (as that of a wheelchair on a ramp).

The POSITION of an object moving along a straight line is uniquely defined by its coordinate with respect to some point of reference. This point is often taken to be the origin.

Distance and Displacement

Distance and displacement are two quantities that may seem to mean the same thing yet have distinctly different definitions and meanings.

Distance is a scalar quantity that refers to "how much ground an object has covered" during its motion. Distance (or farness) is a numerical description of how far apart objects are. In physics or everyday discussion, distance may refer to a physical length, or estimation based on other criteria.

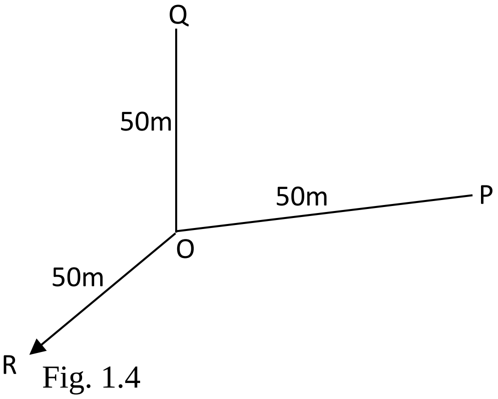


Fig. 1.4

When an object moves, say 50m from a point O to another point P, we say that the distance covered by that object is 50m as shown in fig 1.4. The distance indicated how far the object has moved. However, knowing that distance alone is not sufficient to tell us where or in what direction object has moved. Point R and S are also 50m form O, and we cannot tell which point is the final position of the object. In the study of motion it necessary to specify the direction in which the object is moving.

If the object in fig 1.4 travels 50m northward, the final position is at Q and if eastward, the position is at P, if it moves south-west direction the final position is at R. The distance travelled by an object in a total time interval is the total length of the actual path it covered during the time.

Therefore, with the direction specified, we know the final position of the object. We say that an object distance 50m in a specified direction is the displacement of the object.

Displacement is defined as distance travelled in a specified direction.

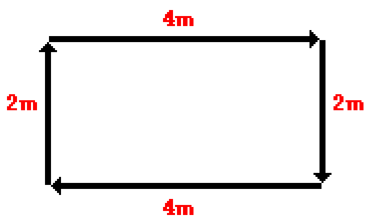


Fig 1.5

It is a vector quantity that refers to "how far out of place an object is"; it is the object's overall change in position. It requires distance and direction to specify it.

Example 1: To see distinction between total distance and displacement, consider the motion depicted in fig 1.5 below. A physics teacher walks 4 meters east, 2 meters south, 4 meters west, and finally 2 meters north

Even though the physics teacher has walked a total distance of 12 meters, her displacement is 0 meters. During the course of her motion, she has "covered 12 meters of ground" (distance = 12 m). Yet when she is finished walking, she is not "out of place" - i.e., there is no displacement for her motion (displacement = 0 m). Displacement, being a vector quantity, must give attention to direction. The 4 meters east *cancels* the 4 meters west; and the 2 meters south *cancels* the 2 meters north. Vector quantities such as displacement are *direction aware*. Scalar quantities such as distance are ignorant of direction. In determining the overall distance travelled by the physics teachers, the various directions of motion can be ignored.

Example 2: Imagine a person walking 500m to east, and then turning around and walking back (west) a distance of 300m, the total distance travelled is 800m but the displacement is only 200m since he is now only 200m from the starting point

Example 3: The diagram in fig. 1.6 shows the position of a cross-country skier at various times. At each of the indicated times, the skier turns around and reverses the direction of travel. In other words, the skier moves from A to B to C to D. Use the diagram to determine the resulting displacement and the distance travelled by the skier during these three minutes. The skier covers a total distance of (180m+140m+100m=420m) while the displacement is 140m

Example 4: a man travels from a town A to another B through a winding road, covering a distance of 300km. if the shortest distance between A and B is 240km, represented by a straight line AB, then the displacement is 240km in the direction of the line AB.

Example 5: If a boy walks 30m eastward and then 40m northward, his displacement is 50m in a northeast direction.

To understand the distinction between distance and displacement, you must know the definitions. You must also know that a vector quantity such as displacement is *direction-aware* and a scalar quantity such as distance is *ignorant of direction*. When an object changes its direction of motion, displacement takes this direction change into account

Distinction between distance and displacement

Distance and displacement are two quantities that may seem to mean the same thing yet have distinctly different definitions and meanings. **Distance** refers to how much ground an object has covered" during its motion while displacement is defined as distance travelled in a specified direction.

Distance	Displacement
It is a scalar quantity; with magnitude only	It is a vector quantity; with magnitude and direction
It is a numerical description of how far apart objects are	it is the object's overall change in position

Speed and Velocity

Just as distance and displacement have distinctly different meanings (despite their similarities), so do speed and velocity.

Speed is a scalar quantity that refers to "how fast an object is moving." In describing the motion of the body, we note both the distance and time it takes to cover that distance. A fast-moving object has a high speed and covers a relatively large distance in a short amount of time. Contrast this to a slow-moving object that has a low speed; it covers a relatively small amount of distance in the same amount of time. An object with no movement at all has a zero speed

Speed of an object can be defined as the rate at which an object covers distance. The average speed during the course of a motion is often computed using the following formula:

$$\text{Thus Average Speed} = \frac{\text{Distance travelled}}{\text{Time of travel}} \qquad (1.1)$$

This indeed is an average speed ($\bar{\upsilon}$) over the distance s. thus

$$\bar{\upsilon} = \frac{s}{t} \qquad (1.2)$$

The SI unit of distance is meter that of time is second. Thus the SI of speed is meter per second (ms^{-1}). Other multiples of that unit are centimeter per second and kilometer per hour.

Example 1: If a bus covers a distance of 200km in 2hours, its average speed is then $\bar{\upsilon} = \frac{200\text{km}}{2\text{hrs}} = 100kmhr$

Average Speed versus Instantaneous Speed

Since a moving object often changes its speed during its motion, it is common to distinguish between the average speed and the instantaneous speed. The distinction is as follows.

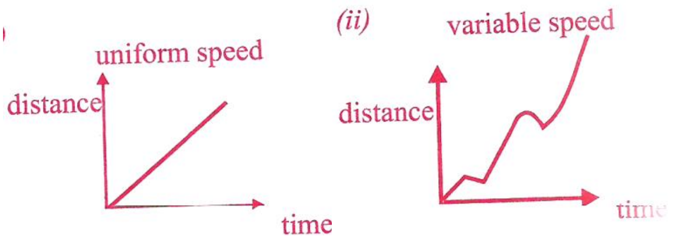
Instantaneous Speed is the speed at any given instant in time.

Average Speed is the average of all instantaneous speeds; found simply by a total distance/time ratio.

You might think of the instantaneous speed as the speed that the speedometer reads at any given instant in time and the average speed as the average of all the speedometer readings during the course of the trip. Since the task of averaging speedometer readings would be quite complicated (and maybe even dangerous), the average speed is more commonly calculated as the total distance/time ratio.

Uniform speed: When a body covers equal distances in equal time interval, no matter how small the time intervals the speed is said to be uniform speed or constant speed.

Variable speed: When a body covers unequal distances in different time interval, the speed is said to be variable speed



Velocity: In everyday language, the words velocity and speed are often used interchangeably. In the study of motion, it is necessary to distinguish between the two. In speed, no direction is specified, but in velocity, it is necessary to specify direction. Since displacement refers to the distance covered in a specified direction, we define velocity in terms of displacement.

Velocity is defined as <u>time</u> rate of change of displacement

$$velocity = \frac{Change\ displacement}{time} \quad , \ v = \frac{s}{t} \qquad (1.3)$$

Velocity is a vector quantity. It is the rate at which an object changes its position. As such, velocity is *direction aware.* When evaluating the velocity of an object, one must keep track of direction. It would not be enough to say that an object has a velocity of 55 km/hr. One must include direction information in order to fully describe the velocity of the object. For instance, you must describe an object's velocity as being 55 km/hr, **east**. This is one of the essential differences between speed and velocity. Speed is a scalar quantity and does not *keep track of direction*; velocity is a vector quantity and is *direction aware*.

An airplane moving towards the west with a speed of 300 km/hr has a velocity of 300 km/hr, west. Note that speed has no direction (it is a scalar) and the velocity at any instant is simply the speed value with a direction.

The average velocity is often computed using this formula

$$Average\ velocity = \frac{\Delta\ position}{time} = \frac{Total\ displacement}{time}$$

Uniform Velocity:

When a body moves with equal displacement in equal time intervals, no matter how small the time intervals may be, the velocity is said to be a uniform velocity or constant velocity. Its unit is meter per second (ms^{-1}). If the body moves round a circular path at constant speed, then it is said to move with non-uniform velocity; because its direction of motion is constantly changed.

Difference between Speed and velocity

Speed is the rate of motion, or the rate of change of position. It is expressed as distance moved (d) per unit of time (t). Speed is a scalar quantity with dimensions distance/time. Speed is measured in the same physical units of measurement as velocity, but does not contain an element of direction. Speed is thus the magnitude component of velocity. Velocity contains both the magnitude and direction components.

Exercises

Q1: While on vacation, Lisa Car travelled a total distance of 440 kilometres. Her trip took 8 hours. What was her average speed?

Solution

To compute her average speed, we simply divide the distance of travel by the time of travel.

$$\bar{\upsilon} = \frac{Total\ distance}{time} = \frac{d}{t} = \frac{440km}{8hr} = 55km/hr$$

Q2: A car travelled at the average speed of $100kmh^{-1}$, what distance does it cover in 5minutes? Leave your answer in SI unit.

Solution

$$1000m \to 1km$$

$$x \to 100km \to x \times 1km = 1000m \times 100km$$

$$\therefore x = \frac{1000m \times 100km}{1km} = 100000m$$

$$3600s \to 1hr$$

$$100kmh^{-1} = \frac{100000m}{3600s} = 27.78ms^{-1}$$

$$60s \to 1\min$$

$$x \to 5\min s \to x \times 1\min = 60s \times 5\min s$$

$$\therefore x = \frac{60s \times 5\min s}{1\min} = 300s$$

$$Speed = \frac{distance}{time}$$

$$Distance = speed \times time = 27.78ms^{-1} \times 300s$$

$$d = 8334m$$

Distance (or displacement) -Time (d-t) Graph

Our study of 1-dimensional kinematics has been concerned with the multiple means by which the motion of objects can be represented. Such means include the use of words, the use of diagrams, the use of numbers, the use of equations, and the use of graphs. This lesson focuses on the use of **Distance or Displacement vs. time graphs** to describe motion. As we will learn, the specific features of the motion of objects are demonstrated by the shape and the slope of the lines on a Distance or Displacement vs. time graph. The first part of this lesson involves a study of the relationship between the shape of a d-t graph and the motion of the object.

To begin, consider a car moving with a **constant, rightward (+) velocity** - say of +10 m/s. If the Distance or Displacement -time data for such a car were graphed, then the resulting graph would look like the graph in fig 2.1.

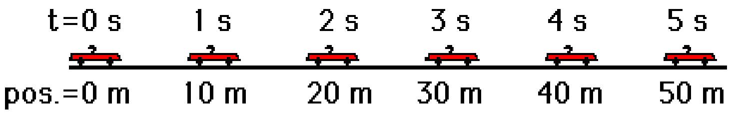


Fig. 2.0

Note that a motion described as a constant, positive velocity results in a line of constant and positive slope when plotted as a Distance or Displacement -time graph.

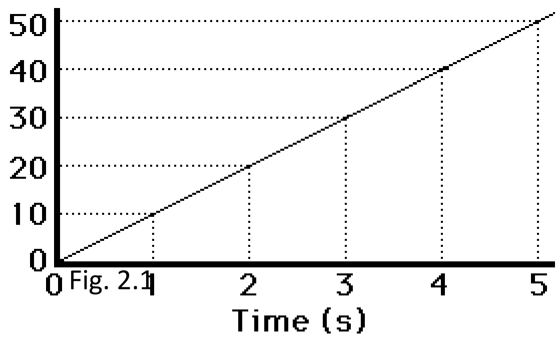


Fig. 2.1

If we measure the distance covered by a moving object at known time intervals (say 2 seconds), and we plot the values of distance on the Y-axis and time on the X-axis of a graph, on joining the points, we obtain the distance (or displacement) – time graph. If the graph is a straight line graph such as in fig 1.8, the speed (or velocity) is uniform since the body covers equal distances in equal time

$$Speed = \frac{distance}{time} = gradient\ or\ the\ slope\ of\ the\ graph$$

$$velocity = \frac{displacement}{time} = gradient\ or\ the\ slope\ of\ the\ graph$$

$$slope = \frac{50-20(m)}{5-2(s)} = \frac{30}{3} = 10m/s$$

Note; any point taken form the slope will give the same value of slope that is speed/velocity. If the speed or velocity is changing the velocity is known as INSTANTANEOUS VELOCITY. It is defined as the velocity at any instant of time. The speedometers of moving vehicles indicate instantaneous velocity

Velocity- Time graph

Now consider a car moving with a **rightward (+), changing velocity** - that is, a car that is moving rightward but speeding up or *accelerating*.

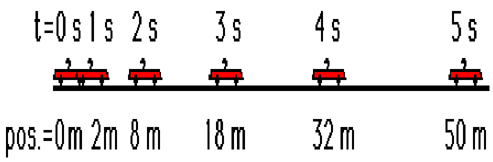
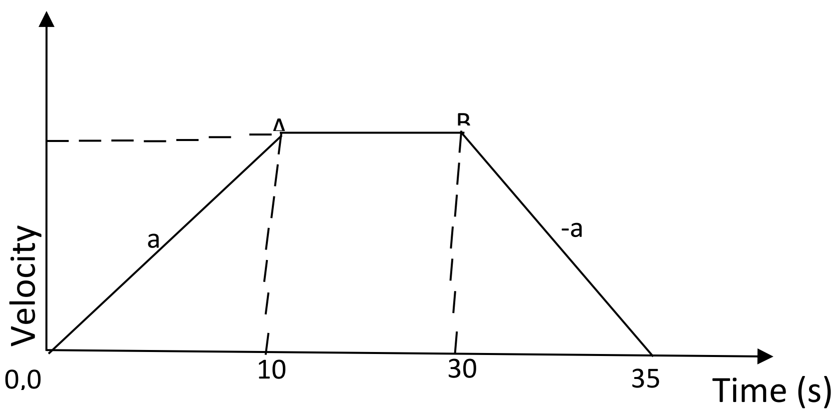


Fig. 2.2

If the velocity -time data for a car in Fig. 2.2 were graphed, then the resulting graph would look like the graph in Fig. 2.3, 2.4 Note that a motion described as a changing, positive velocity results in a line of changing and positive slope when plotted as a velocity -time graph.

Slope or gradient of velocity time graph is the acceleration. The quantities that can be obtained from velocity-time graph are; acceleration, deceleration, distance travelled, instantaneous velocity and average velocity



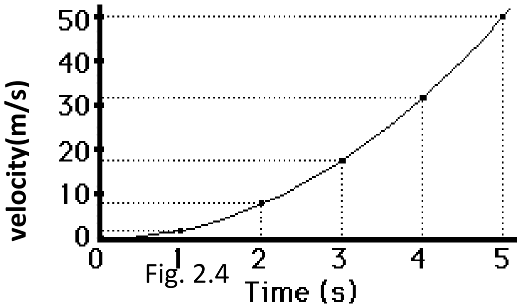


Fig. 2.3

Fig. 2.4

Acceleration is defined as time rate of change in increase velocity. Its unit is meter-per-second-per second (m/s^{-2}) this means that a car that speeds up, turns left and turns right is undergoing acceleration but when it slows down its velocity decreases with time, it is known as **Retardation**. Retardation is negative acceleration.

$$Acceleration\ (a)\ or\ OA = \frac{velocity\ change}{time\ taken\ for\ change} = \frac{final\ velocity - initial\ velocity}{time} = \frac{V-U}{t} \therefore V = u + at$$

(1.5)

Example 1: A car starts from rest and accelerates uniformly for 10secs; until it attains a velocity of 25m/s it then travels with uniform velocity for 20s before decelerating uniformly to rest in 5secs. (i) Calculate the acceleration during the first 10s; (ii) Calculate the acceleration during the last 5secs; (iii) Sketch a graph of the motion and calculate the total distance covered throughout the motion.

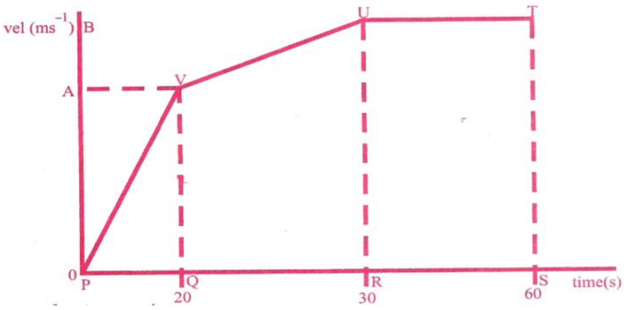
$$(i)\ a = \frac{V-U}{t} = \frac{25-0}{10} = 2.5ms^2$$

$$(ii)\ Deceleration\ (a) = \frac{final\ velocity - initial\ velocity}{time} = \frac{V-U}{t} = \frac{0-25}{10} = -5ms^2$$

$$(iii)\ Total\ distance\ travelled = \frac{1}{2}(sum\ of\ \ parallel\ side) \times height$$

$$= \frac{1}{2}((30-10)+35) \times 25 = \frac{1}{2}(20+35) \times 25 = 687.5m$$

Example 2: A body at rest is given an initial uniform acceleration of $6.0m/s^{-2}$ for 20 sec, after which accelerated again to $4.0m/s^{-2}$ for the next 10s. The body maintains the speed attained for 30s. Draw the velocity-time graph of motion using the information given above. From the graph, calculate the (i) maximum speed attained during the motion; (ii) total distance covered during the first 30s; (iii) average speed during the same time interval as in (ii) above;



(i) Maximum Speed

Velocity at A $V = u + at = 0 + 6 \times 20 = 120m/s$

Velocity at B $V = u + at = 120 + 4 \times 10 = 160m/s$ = Maximum speed

(ii) Total distance travelled during the first 30 seconds

$= Area\ of\ triangle PQV + Area\ of\ trapezium\ QRUV$

$$=\frac{1}{2}\times b\times h+\frac{1}{2}(sum\ of\ \ parallel\ sides)\times height$$

$$=\frac{1}{2}\times 20\times 120+\frac{1}{2}(120+160)\times 10=10\times 120+140\times 10$$

$$=1200+1400=2600m$$

(iii) Average speed in the first 30 seconds

$$=\frac{Distance\ travelled\ in\ 30s}{time\ taken}=\frac{2600m}{30s}=86.67m/s$$

Measure of Uniform/Non-uniform Acceleration

With regard to the acceleration and deceleration of local motion, however, it is to be noted that there are two ways in which a motion may be accelerated or decelerated: namely, uniformly, or non-uniformly. For any motion whatever is *uniformly accelerated* if, in each of any equal parts of the time whatsoever, it acquires an equal increment of velocity. But a motion is *non-uniformly accelerated or decelerated*, when it acquires or loses a greater increment of velocity in one part of the time than in another equal part.

Uniform acceleration

Uniform or *constant* acceleration is a type of motion in which the velocity of an object changes by an equal amount in every equal time period. Uniform acceleration occurs when the speed of an object changes at a constant rate. The acceleration is the same over time. By relating acceleration to other variables such as speed, time and distance we are able to manipulate data in many ways.

A frequently cited example of uniform acceleration is that of an object in free fall in a uniform gravitational field. The acceleration of a falling body in the absence of resistances to motion is dependent only on the gravitational field strength g (also called *acceleration due to gravity*). By Newton's Second Law the force, F, acting on a body is given by: F = mg

Due to the simple algebraic properties of constant acceleration in the one-dimensional case (that is, the case of acceleration aligned with the initial velocity), there are simple formulas that relate the following quantities: displacement, initial velocity, final velocity, acceleration, and time:

$$a=\frac{v-u}{t} \qquad (1.6)$$

$$V=u+at \qquad (1.7)$$

Rectilinear Acceleration

In physics, **acceleration** is the rate of change of velocity with time. In one dimension, acceleration is the rate at which something speeds up or slows down. However, since velocity is a vector, acceleration describes the rate of change of both the magnitude and the direction of velocity. Acceleration has the dimensions L T^{-2}. In SI units, acceleration is measured in meters per second squared (m/s^2). (Negative acceleration i.e. retardation, also has the same dimensions/units.) Proper acceleration, the acceleration of a body relative to a free-fall condition, is measured by an instrument called an accelerometer.

In common speech, the term *acceleration* is used for an increase in speed (the magnitude of velocity); a decrease in speed is called *deceleration*. In physics, a change in the direction of velocity also is acceleration: for rotary motion, the change in direction of velocity results in *centripetal (toward the centre) acceleration*; whereas the rate of change of speed is a *tangential acceleration*

In classical mechanics, for a body with constant mass, the acceleration of the body is proportional to the net force acting on it (Newton's second law):

$$F=ma\rightarrow a=F/m$$

where **F** is the resultant force acting on the body, *m* is the mass of the body, and **a** is its acceleration.

Average acceleration is the change in velocity ($\Delta \mathbf{v}$) divided by the change in time (Δt). Instantaneous acceleration is the acceleration at a specific point in time which is for a very short interval of time as Δt approaches zero.

Derivation of equations of linear motion

The three equations of linear motions are

$v = u + at$

$s = ut + \frac{1}{2}at^2$

$v^2 = u^2 + 2as$

First equation

Acceleration (a) is defined as $a = \frac{change\ in\ velocity}{time\ interval}$

$a = \frac{\Delta v}{\Delta t} = \frac{v - u}{t}$

$at = V - U$ or $V = U + at$ ……………………………………………(1)

Second Equation

To derive the second equation of motion, let s be the distance covered in a time, with the initial and final velocities given as u and v respectively.

Average velocity $\bar{v} = \frac{u + v}{2}$

From equation (1) v = u +at, hence

$$\bar{V} = \frac{u + u + at}{2} \Rightarrow \frac{2u}{2} + \frac{1}{2}at \Rightarrow u + \frac{1}{2}at$$

But Total distance covered is average velocity x time = $\bar{V}$ x t

$s = (u + \frac{1}{2}at) \times t = ut + \frac{1}{2}at^2$ ………………………………………………………………(2)

Third equation of Motion

We can obtain the third equation of motion with the use of equations (1) and (2)

We have v = u + at……………………………………………………..(1)

Squaring both sides $v^2 = (u + at)^2 \Rightarrow u^2 + uat + uat + a^2t^2 \Rightarrow u^2 + 2uat + a^2t^2$

$= u^2 + 2uat + a^2t^2 \Rightarrow u^2 + 2a(ut + \frac{1}{2}at^2)$

$s = ut + \frac{1}{2}at^2$ *from equation* (2) $\therefore v^2 = u^2 + 2as$ ………………………………………(3)

Motion under gravity- Free fall

Galileo discovered in 1950 that all dead objects fall on earth at the same acceleration called the acceleration due to gravity in the absence of air resistance. It is given the symbol g and has an average value of 9.8 ms^{-2} on earth. For falling object air resistance opposes the acceleration due to gravity but with velocity. So when an object falls in air it,

(a) initially accelerates due to gravity,

(b) the air resistance increase as the velocity of the body increases,

(c) At a certain stage therefore the resistance forces become equal to weight and the velocity achieved at this point is maintained- it reached its terminal velocity.

THREE facts about acceleration of a free falling object due to gravity

When an object falls in air it,

(a) Its magnitude decreases with altitude (height),

(b) It varies with latitude

(c) At the equator, its value is about $10m/s^2$

(d) Its value on earth is about 6 times that on the moon/ greater than that on the moon

(e) It is a vector quantity

The same five equation holds as in uniform accelerated motion UAM with (a) replaced by (-g)

$v = u + at$	$v = u - gt$
$s = \frac{1}{2}(u+v)t$	$s = \frac{1}{2}(u+v)t$
$s = ut + \frac{1}{2}at^2$	$s = ut - \frac{1}{2}gt^2$
$v^2 = u^2 + 2as$	$v^2 = u^2 - 2gs$
$s = vt - \frac{1}{2}at$	$s = vt + \frac{1}{2}gt$

If a body is thrown from a point with initial velocity u:

(i) at the maximum height v = 0,

(ii) time up = time down,

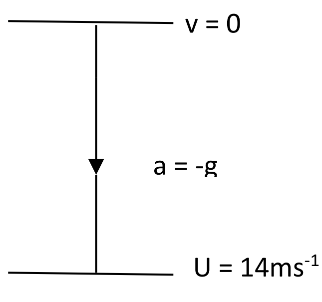
(iii) velocity on returning to the starting point is equal but opposite to the velocity of projection, i.e. it is –u

(iv) at the maximum height although the body has zero velocity it is still accelerating, i.e. a = -g

Note; Dropped means that the starting velocity is zero

Example 1: A body is thrown up at $14ms^{-1}$. How high does it go? What time does it take to reach the highest point? What is the time of the round trip and the speed of return? ($9.8\ m\ s^{-2}$)

SOLUTION



V = 0 ms^{-1}, a = -g = 9.8 ms^{-2}, s = ? U = 14ms^{-1}

Using the relation

$$v^2 = u^2 + 2as \Rightarrow 0 = 196 + 2(-9.8)s \Rightarrow 19.6s = 196$$

$$\therefore s = 10m$$

$$v = u + at \Rightarrow 0 = 14 - 9.8t \Rightarrow 9.8t = 14$$

$$\therefore t = \frac{14}{9.8} = \frac{10}{7}s$$

Time down = time up $\Rightarrow$ Time for round trip

$$2 \times \frac{10}{7}s = \frac{20}{7}s$$

Example 2: A man can jump 2m on the earth. Find his initial speed. How high can he jump on the moon? Acceleration due to gravity on the earth = $9.8\ m\ s^{-2}$; acceleration due to gravity on the moon $1.6\ m\ s^{-2}$)

SOLUTION

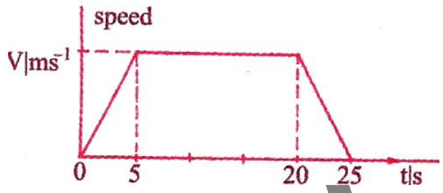
Earth	Moon
V = 0 ms^{-1}, s = +2m, a = -g = -9.8 ms^{-2}, u = ? u = 6.3 ms^{-1}	V = 0 ms^{-1}, s = +2m, a = -g = -1.6 ms^{-2},

Assignments

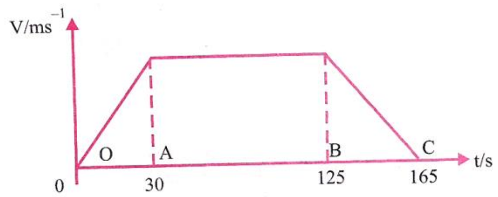
1. Define velocity and acceleration
2. List TWO physical quantities that can be deduced from a velocity-Time graph

<u>Assignment</u>

1. Using a suitable diagram, explain how the following can be obtained from a velocity-Time graph;
2. Acceleration (ii) total distance covered
3. Explain the following; uniform velocity and average speed
4. A car starts from rest and accelerates uniformly for 5secs; until it attains a velocity of 30m/s it then travels with uniform velocity for 15s before decelerating uniformly to rest in 10secs. (i) Sketch the graph of motion.
5. Using the graph in (i) above, Calculate (iia) the acceleration during the first 5s; (iib) deceleration during the last 10secs; (iic) Total distance covered throughout the motion.
6. Sketch a distance-time graph for a particle moving in a straight line with variable speed.
7. A body starts from rest and travels a distance of 120, 300 and 180m in successive equal time interval of 12s. During each interval the body is uniformly accelerated. (i) Calculate the velocity of the body at end of EACH successive time interval; (ii) Sketch a velocity-Time graph for the motion.
8. The diagram below shows the speed-time graph of a car covered a total distance of 600m in 25s, Calculate the maximum speed.



9. In the velocity-Time graph shown below, the constant acceleration during the interval OA is 4 m/s^2. Determine the retardation during the interval BC.



10. A boat sails from a certain port in the direction N 30^oW. After the boat has sailed 20km, how far is it west of the port?
11. A Cyclist travels 10 km south, and then 8 km east, Find the Cyclist bearing from her starting point to the nearest degree.
12. An eagle drops 35m to catch a fish. With what speed does it strike the water?
13. A rocket is launched at a speed of 2.1 x 10^3 ms^{-1}. How high does it rise?
14. A flower pot slips off a window ledge 2.94 m above a woman. How much time does she have to get out of the way if a man shouts ‘Get out of the way’ the instant the pot falls?
15. A rocket is dropped from rest from the top a cliff. Two seconds later a splash is heard in the water below. Find the height of the cliff.
16. An object is thrown up at 98 ms-^{1}. How high does it take to reach its highest point? How long does it take to return to the point of projection? With what speed does it return?
17. Calculate the acceleration of a body that moved from rest to a velocity of 30m/s after 5s
18. Suppose a car moves from a velocity of 20 m/s to velocity of 30 m/s in 5 seconds, its calculate its average acceleration.

LESSON 5 NOTE

Definition of motion

In physics, motion means a continuous change in the position of a body relative to a reference point, as measured by a particular observer in a particular frame of reference. In other words, any physical movement or change in position or place. Motion is the time dependent. It is the change in position associated with a body with time.

Types of Motion

There are **eight (8)** types of motion:

- Translational motion
- Rotational motion
- Oscillatory or Vibratory motion
- Random motion
- Rectilinear motion
- Spin motion
- Orbital motion
- Circular motion

Translational Motion

In translational motion the particle moves from one point in space to another without rotating. It is the movement of the whole body from one position to another, that is, every point in the body remains relatively fixed to one another. Each path of an object undergoing pure translational motion follows the same path. This motion may be along a straight line known as rectilinear motion examples a car moving on a straight road and a falling stone or along a curved path known as curvilinear motion examples a car negotiating a curve bend, a Diver in motion and a bee flying from on flower to another.

Rotational Motion

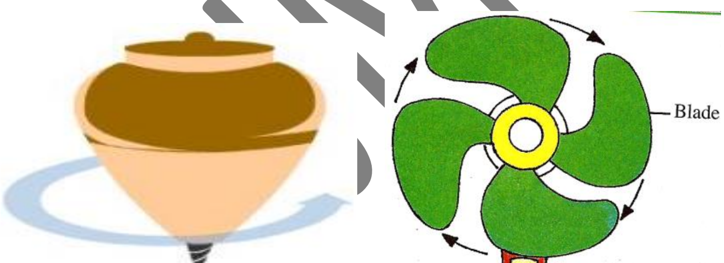
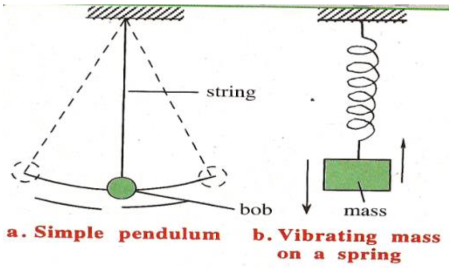


Fig 1.2a Rotational Motion Fig 1.2b an electric fan

Rotational motion is the turning of a body around a fixed point. That is, the particles of the body describe concentric circles and that the centre these circles all lay on a line called the axis of rotation. Examples are blade of electric fans, the earth rotating about its axis, cricket ball spinning about its axis and the rotating wheel of a moving car.

Oscillatory or Vibratory Motion



Oscillatory or Vibratory Motion is the periodic to and fro movement of an object about a central position or fixed point. That is, it repeats itself. Examples are bob of a pendulum, the motion of a rocking chair, a diving board, the strings of a plucked guitar, the prongs of a turning fork struck with hard object and the vertical motion of a disturbed mass on a spiral spring

Random motion

Random motion is the irregular or haphazard or disorderly movement of an object with no preferred direction or orientation or no definite pattern. Particles that undergo random motion collide with one another. Examples are the movement of footballers in the field, motion of Brownian motion.

Brownian motion

In 1827 Robert Brown first observed a direct effect of the movement of molecules. He was looking through the microscope at some tiny pollen particles in water, he found, to his surprise that these particle were in a continual, haphazard motion. Many years afterwards it was realised that these random motion of these particles was caused by bombardment from moving water molecules. This kind of motion is shown by the smoke particles suspended in the air. This random motion is called **Brownian motion** after its discoverer. **Brownian motion** is defined as an irregular motion of a particle of various kinds suspended in water, or smoke particles suspended in air, or motion of gas particle.

Nowadays Brownian motion can be observed in a school laboratory by looking at smoke from a burning straw or pieces of string, trapped in small glass cell under a microscope. When lit from the side, the particles of the smoke are seen in continual random movement.

Brownian motions are important for two reasons. First, it is the evidence for the existence of molecules, which are too small to be observed directly. Second, it is evidence that molecules are not still, but are in continual motion.

In reality, object in motion often exhibit more than one type of motion at the same time. The motion of a body consists of the combination of two of the above, e.g., translation and rotation are involved in a ping-pong ball spinning through space from one player to another. The wheels of a moving car undergo both translational and rotational motion.

Relative motion

Motion as we know is a continuous change in the position of a body relative to a reference point. This implies that every measurement must be made with respect to a reference point. For example a person sitting on a bus travelling past a school boy standing at the bus stop has a relative speed or velocity with respect the earth and bus. The person on a moving bus has a relative speed with respect to the earth which is the same as that of the bus. If the speed of the bus and the person is in the same direction, the speed of the person relative to the earth is greater than the speed of the bus. But in different direction the relative speed of the person is less.

Example1: The relative speed or velocity of a boy at the back seat moving towards the driver at a speed of 10km/hr in a bus moving with the speed of 120km/hr is 120+10 = 120km/hr

Example 2: If the same boy moves back to his back seat with the same speed. The relative speed or velocity is less 120-10 110km/hr.

Example 3: If the boy seating in the same moving bus looks down, he observes that that the bus appear to be stationary. This implies that his relative velocity with respect to the earth is Zero because he has the same speed with the bus. That is 120-120 = 0 km/hr

Causes of Motion

The influences which cause changes in the motion of objects are forces and torques. The effects of forces on objects are described by Newton's Laws. A force may be defined as any influence which tends to change the motion of an object. The relationship between force, mass, and acceleration is given by Newton's Second Law:

$$F_{\text{net external}} = ma$$

Net force is unbalanced force that produces acceleration of a body.

Newton's First Law states that an object will continue at rest or in motion in a straight line at constant velocity unless acted upon by an external force. Newton's Third Law states that all forces in nature occur in pairs of forces which are equal in magnitude and opposite in direction.

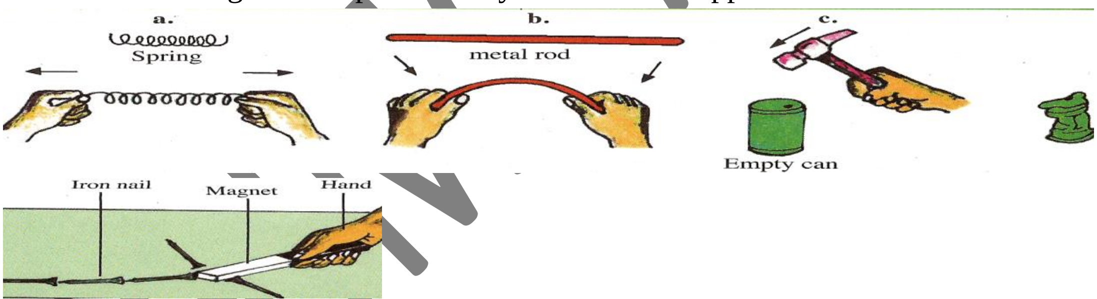
Force

Force is thought of as any influence which tends to change the motion of an object. Our present understanding is that there are four fundamental forces in the universe, the gravity force, the nuclear weak force, the electromagnetic force, and the nuclear strong force in ascending order of strength. In mechanics, forces are seen as the causes of linear motion, whereas the causes of rotational motion are called torques. The action of forces in causing motion is described by Newton's Laws under ordinary conditions, although there are notable exceptions. Forces are inherently vector quantities, requiring vector addition to combine them. The SI unit for force is the Newton, which is defined by Newton = kg m/s^2 as may be seen from Newton's second law.

EFFECT OF FORCE

Effects of force include the following:

1. Force move a body from on point to another
2. Change its direction of motion
3. Make it slow down or stop moving altogether
4. Distort or change the shape of a body to which it is applied.



In Fig. 1.6 force can increase the length of a spring, bend a rod, distort the shape of an empty can or move body at rest.

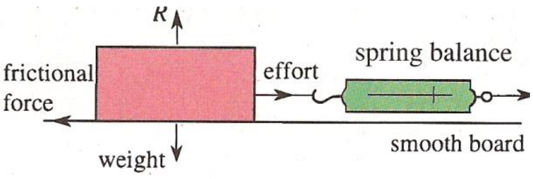
TYPES OF FORCES

There are two main types of forces namely **Contact and Non- Contact or force field**

In physics a **contact forces** is a force that acts at the point of contact between two objects, in contrast to body forces. That is, they are forces which are in contact or in touch with the body to which they are applied. Contact forces are described by Newton's laws of motion.

They are responsible for most visible interactions between macroscopic collections of matter. Examples of contact forces are pushing a car up a hill and kicking a ball. In the first case the force is continuously applied by the person on the car, while in the second case the force is delivered in a short impulse. The most common examples of contact forces include friction, normal force or reaction, and tension, push, pull

Friction



Friction is the force resisting the relative motion of solid surfaces, fluid layers, and/or material elements sliding against each other. Frictional forces are forces that are at tangential to the surface of separation between two bodies in contact.

Definition of friction

Fiction is defined as a force which acts at the surface of separation between two objects in contact and tends to oppose the motion of one over the other.

It is a force of opposition and does not appear unless there is a relative motion, or force tending to produce motion, it always appears to oppose the motion or the force tending to produce the motion. Some frictional force has to be overcome before an object can move over another. This is known as Static or limiting friction.

Static or limiting friction

Static friction is friction between two solid objects that are not moving relative to each other. It is the friction that prevents an object from sliding down a sloped surface. The static or limiting friction force is the maximum force that must be overcome by an applied force before an object can move.

An example of static friction is the force that prevents a car wheel from slipping as it rolls on the ground. Even though the wheel is in motion, the patch of the tyre in contact with the ground is stationary relative to the ground, so it is static rather than kinetic friction.

The maximum possible friction force between two surfaces before sliding begins is the product of the coefficient of static friction and the normal force:

$$F = \mu_s R .$$

Where μ_s is the coefficient of static friction, R the normal reaction.

Coefficient of friction

The 'coefficient of friction' (COF), also known as a 'frictional coefficient' or 'friction coefficient' and symbolized by the Greek letter μ, is a dimensionless scalar value which describes the ratio of the force of friction between two bodies and the force pressing them together. The coefficient of friction depends on the materials used; for example, ice on steel has a low coefficient of friction, while rubber on pavement has a high coefficient of friction. Coefficients of friction range from near zero to greater than.

The constant μ is known as the coefficient of friction

$$\mu = \frac{F}{R}$$

Coefficient of friction(μ) is defined as the ratio;

$$\mu = \frac{frictional\ force\ F}{\substack{normal\ reaction\ between \\ the\ two\ surfaces\ in\ contact\ R}}$$

For surfaces at rest relative to each other $\mu = \mu_s$, where μ_s is the *coefficient of static friction*. This is usually larger than its kinetic counterpart.

Coefficient of static friction μ is defined as the ratio of frictional force and normal reaction

$$\mu_s = \frac{fictional\ \ force}{normal\ reaction} = \frac{F}{R}$$

Kinetic (or dynamic) friction

Kinetic (or dynamic) friction occurs when two objects are moving relative to each other and rub together (like a sled on the ground). The coefficient of kinetic friction is typically denoted as μ_k, and is usually less than the coefficient of static friction for the same materials.

The Kinetic (or dynamic) friction, is defined as the force that must be overcome so that a body can move with uniform speed over another body.

For surfaces in relative motion $\mu = \mu_k$, where μ_k is the *coefficient of kinetic friction*.

When there is no sliding occurring, the friction force can have any value from zero up to F_{max}.

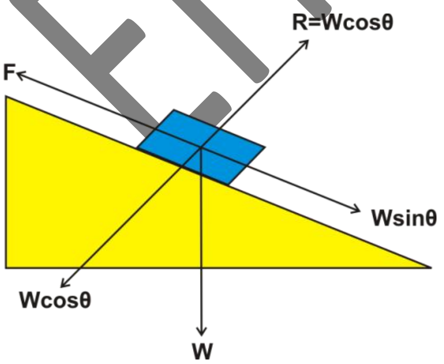
Any force larger than F_{max} overcomes the force of static friction and causes sliding to occur. The instant sliding occurs; static friction is no longer applicable. The friction between the two surfaces is then called kinetic friction.

The coefficient of static friction, typically denoted as μ_s, is usually higher than the coefficient of kinetic friction μ_k.

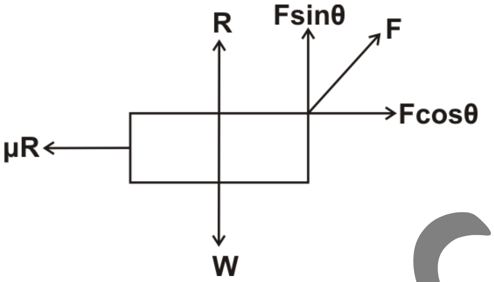
The normal force

The normal force is defined as the net force compressing two parallel surfaces together; and its direction is perpendicular to the surfaces. In the simple case fig 1.7 of a mass resting on a horizontal surface, the only component of the normal force is the force due to gravity, where. W = mg

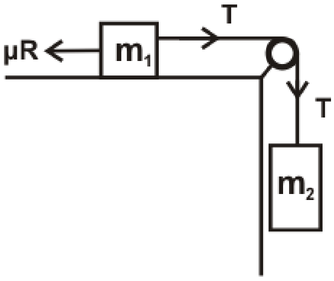
<u>Friction on Inclined Plane and Connected Bodies</u>



From the diagram above, $F = Wsin\theta$ and $R = Wcos\theta$ (Examples to be solved in class)



From the diagram above, $Fcos\theta = \mu R$ and $W = R + Fsin\theta$ (Examples to be solved in class)



From the diagram above, $T - \mu R = m_1 a$ and $W - T = m_2 a$ (Examples to be solved in class)

TYPES OF FRICTION

There are several types of friction:

- **Dry friction** resists relative lateral motion of two solid surfaces in contact. Dry friction is subdivided into *static friction* between non-moving surfaces, and *kinetic friction* between moving surfaces.
- **Fluid friction** describes the friction between layers within a viscous fluid that are moving relative to each other.
- **Lubricated friction** is a case of fluid friction where a fluid separates two solid surfaces.
- **Skin friction** is a component of drag, the force resisting the motion of a solid body through a fluid.
- **Internal friction** is the force resisting motion between the elements making up a solid material while it undergoes deformation.

Laws friction

The elementary properties of sliding (kinetic) friction were discovered by experiment in the 15th to 18th centuries and were expressed as three empirical laws:

- **Amontons' First Law**: The force of friction is directly proportional to the applied load.
- **Amontons' Second Law**: The force of friction is independent of the apparent area of contact.
- **Coulomb's Law of Friction**: Kinetic friction is independent of the sliding velocity.

Amontons' 2nd Law is an idealization assuming perfectly rigid and inelastic materials. For example, wider tires on cars provide more traction than narrow tires for a given vehicle mass because of surface deformation of the

Advantages of friction

In some situations, friction is very important and beneficial. There are many things that you could not do without the force of friction.

1. Walking-You cannot walk without the friction between your shoes and the ground. As you try to step forward, you push your foot backward. Friction holds your shoe to the ground, allowing you to walk.

2. Writing -Writing with a pencil requires friction. You cannot hold a pencil in your hand without friction. It would slip off when you tried to hold it to write. A pencil eraser uses friction to rub off mistakes written in pencil lead. Rubbing the eraser on the lead wears out the eraser due to friction, while the particles worn off gather up the pencil lead from the paper.

3. Driving car -Your car would not start moving if it was not for the friction of the tyres against the street. With no friction, the tyres would just spin. Likewise, you cannot stop without the friction of the brakes and the tyres.

Disadvantages of friction

1. Makes movement difficult -Any time you want to move an object, friction can make the job more difficult. Excess friction can make it difficult to slide a box across the floor, ride a bicycle or walk through deep snow. Oil is needed to lubricate the engine and allow its parts to move easily. Oil and ball bearings are also used in the wheels, so they will turn with little friction.
2. Friction wastes energy - In any type of vehicles as a car, boat or airplane--excess friction means that extra fuel must be used to power the vehicle. In other words, fuel or energy is being wasted because of the friction. Fluid friction or air resistance can greatly reduce the gas mileage in an automobile.
3. Friction causes heating of engine parts -The Law of Conservation of Energy states that the amount of energy remains constant. Thus, the energy that is "lost" to friction in trying to move an object is really turned to heat energy. Besides the problem of losing energy to heat, there is also the threat of a part overheating due to friction. This can cause damage to a machine.
4. Friction Wears and tears things out -Any device that has moving parts can wear out rapidly due to friction.

Method of Reducing friction

There are three ways of reduction of friction namely;

1. Use of devices such as wheels, ball bearings, roller bearings, and air cushion or other types of fluid bearings can change sliding friction into a much smaller type of rolling friction

2. The streamlining of body shapes of moving objects and lubricants.

3. The use of Lubricants, such as oil, water, or grease, which is placed between the two surfaces, often dramatically lessening the coefficient of friction, and graphite

4. Smoothening

Uses of Friction

Although you normally hear about trying to reduce or eliminate friction, it actually has some important uses.

Non- contact force or Force field

A non-contact force or force fields are forces applied to an object by another body that is not in direct contact with it. That is they are force whose sources do not require contact with the body to which they are applied. The most common example of a non-contact force is gravity. A non-contact force is different from a contact force, which is a force applied to a body by another body that *is* in contact with it. However it is to be noted that the origin of all contact forces (such as, for example, friction) can be traced to non-contact forces.

The four known fundamental forces are all non-contact forces:

- **Gravitational force**, is a non-contact force between two objects, and related to the concept of mass. The force exerted on each body by the other through weight is proportional to the mass of the first body m_1 times the mass of the second body m_2 divided by the square of the distance between them r^2. $F_g = \frac{M_1 M_2}{r^2}$. The direction of the force is from the body acted on towards the body applying the force. A human body's weight is a non-contact force exerted by the Earth on their mass.

- Electromagnetism is the force that causes the interaction between electrically charged particles; the areas in which this happens are called electromagnetic fields. Examples of this force include: electricity, magnetism, radio waves, microwaves, infrared, visible light, X-rays and gamma rays.

- Strong nuclear force: Unlike Gravity and electromagnetism, the strong nuclear force is a short distance force that takes place between fundamental particles within a nucleus. It is charge independent and acts equally between a proton and a proton, a neutron and a neutron, and a proton and a neutron. The strong nuclear force is the strongest force in nature; however, its range is small (acting only over distances of the order of 10^{-15} m).

- Weak nuclear force: The weak nuclear force appears only in certain nuclear processes like β decay of a nucleus, in which the nucleus emits a β particle and an uncharged particle called a neutrino. Both the strong and weak forces form an important part of quantum mechanics.

Summary

In the Standard Model of modern physics, the four fundamental forces of nature are known to be non-contact forces. The strong and weak forces primarily deal with forces within atoms, while gravitational effects are only obvious on a macroscopic scale. Molecular and quantum physics show that the electromagnetic force is the fundamental interaction responsible for contact forces. The interaction between macroscopic objects can be roughly described as resulting from the electromagnetic interactions between protons and electrons of the atomic constituents of these objects. Everyday objects do not *actually* touch each other; rather contact forces are the result of the interactions of the electrons at or near the surfaces of the objects (exchange force).

Circular motion

In physics, circular motion is rotation along a circle: a circular path or a circular orbit. It can be uniform, that is, with constant angular rate of rotation, or non-uniform, that is, with a changing rate of rotation.

Examples of circular motion include:

1. An artificial satellite orbiting the Earth in geosynchronous orbit,

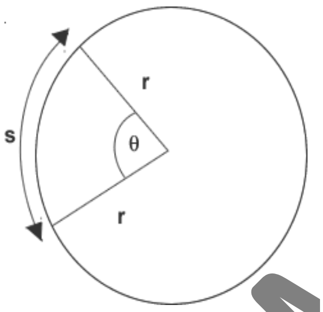
2. A stone which is tied to a rope and is being swung in circles.

3. A race car turning through a curve in a race track,

4. An electron moving perpendicular to a uniform magnetic field,

5. A gear turning inside a mechanism.

Formulas for uniform circular motion



Circular Motion

A body that travels equal distances in equal amounts of time along a circular path has constant speed but not constant velocity. This is because velocity is a vector and thus it h magnitude as well as direction

The velocity of P is directed along the tangent at P. The speed remains constant but th velocity has changed. We know that if the velocity changes with time then the ball on th string is also accelerating.

The angle in radians is defined by. If $s = r$ then θ=1 rad. Therefore, 1 rad is the angle subtend at the center of a circle by an arc equal in length to the radius. When $s = 2\pi r$ then $\theta = 2\pi$ radians=360°. Therefore, 1 rad = 360°/2 π=57.3° $\theta = s/r$**(1)**

Derivation

Consider a body moving uniformly from A to B in time t so that OA rotates through a small angle θ.

The angular velocity, ω of the body about O is $\omega = \dfrac{\theta}{t}$

If arc AB has length s and v is the constant speed of the body, $v = \dfrac{s}{t}$

But $s = r\theta$

So, $v = r\theta / t$ and $\omega = \theta / t$,

therefore $v = r\omega$

Angular Velocity

The speed of a body moving in a circle can be specified either by its speed along the tangent at any instant (linear speed) or by the angular velocity. This is the angle swept out in unit time by the radius joining the body to the centre. It is measured in [rad s^{-1}]

For motion in a circle of radius *r*, the circumference of the circle is $C = 2\pi r$. If the period for one rotation is *T*, the angular rate of rotation, also known as angular velocity, ω is:

$$\omega = \frac{2\pi}{T}$$

The speed of the object traveling the circle is:

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

The angle θ swept out in a time *t* is:

$$\theta = 2\pi \frac{t}{T} = \omega t$$

Acceleration

The expression for the acceleration of an object moving in circular motion of radius *r* moving at a constant speed *v* is derived as follows.

If it travels from A to B in a short interval of time δt then, since speed = distance x time, arc AB = $v\delta t$. Also by the definition of angle in radians, arc AB = $r\,\delta\theta = v\,\delta t$.

So, $v\,\delta t / r = \delta\theta$.

a = change in velocity/time interval = $(v^2\delta t/r)/\delta t = v^2/r$. Therefore $a = v^2/r$ also $a = \omega^2 r$.

$a = v^2/r$

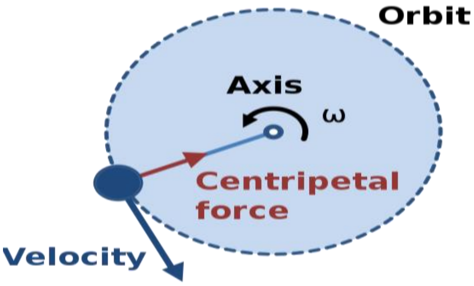
$a = r\,\omega^2$

The direction of the acceleration is toward the centre O as can be seen if δt is made so that A and B all but coincide; XZ is then perpendicular to $\mathbf{v}_A$ (or $\mathbf{v}_B$) is along AO or BO. We say the body has a *centripetal acceleration* (i.e. centre seeking). Does a body moving uniformly in a circle have constant acceleration?

Centripetal Force

Other examples of circular motion will be discussed in the following sections. In all cases it is important to appreciate that the forces acting on the body must provide a resultant force of magnitude mv^2/r toward the centre.

Since a body moving in a circle (or circular arc) is accelerating, it follows that from Newton's 2nd law that there must be force acting on it to cause the acceleration. This force will also be directed toward the centre and is called the *centripetal force*. It causes the



Centripetal force is a force that makes a body follows a curved path: it is always directed orthogonal to the velocity of the body, toward the instantaneous center of curvature of the path

The magnitude of the centripetal force is given by:
$F = ma = mv^2/r$

Where m is the mass of the body and v is the speed in the circular path of radius r. If the angular velocity of the body is ω we can also say since $v=r\omega$.
$F = ma = mr\omega^2$

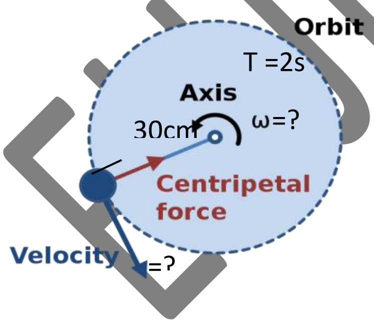
Centrifugal force

Centrifugal force represents the effects of inertia that arise in connection with rotation and which are experienced as an outward force away from the center of rotation. The term *centrifugal force* is used to refer to one of two distinct concepts: an inertial force and a reaction force corresponding to a centripetal force. The concept of centrifugal force is applied in rotating devices such as centrifuges, centrifugal pumps, centrifugal governors, centrifugal clutches, etc., as well as in centrifugal railways, planetary orbits, banked curves, etc.

Exercises

A stone whirled at the end of a rope 30cm long, makes ten complete revolutions in 2 seconds. Find: 1.The angular velocity in radians per second, 2. the linear speed, 3. the distance covered in 5 seconds

Solution



(i) The angle covered in 1 revolution is given by $\theta = 360^o \ or \ 2\pi \ radians$

Angle covered in 10rev = $2\pi \times 10 \ radian$

$= 20\pi rad.$

Time for 10 revs. = 2 seconds

Angular velocity $\omega = \frac{\theta}{t} = \frac{20\pi rad.}{2s}$

$= 10\pi radians \ per \ second$

$= 10 \times 3.14 = 31.4 rad.S^{-1}$

(ii) Linear speed is given by

$v = r\omega$

$= 30cm \ \times 31.4 \, rads^{-1}$

$= 942 cm.s^{-1}$

Distance covered in 5 seconds is given by

$s = vt$

$= 0.942 \ \times 5$

$= 4.71m$

$= 0.942ms^{-1}$ N/B radian is dimensionless because it is the ratio between two lengths,

so cms^{-1} x $rad.S^{-1}$ = cm. S^{-1}

(2) A mass of 10kg is moving in a circular path of radius 2m with a uniform speed of $50ms^{-1}$. Find the centripetal acceleration and the corresponding centripetal force

SOLUTION

Centripetal acceleration is given by

$$a = \frac{v^2}{r}$$
$$= \frac{50 \times 50}{2}$$
$$= 1250ms^{-1}$$

Centripetal force is given by

$$F = mass \times acceleration$$
$$= 10kg \times 1250ms^{-2}$$
$$= 12500kg.m.s^{-2}$$
$$= 12500newtons$$

Evaluation: 1. Define motion, 2. List TWO examples of random motions, translational and oscillatory, 4. differentiate between random and oscillatory motion, 5. state the cause of motion and explain the effect, 6. Define force, 7. explain briefly how it can causes motion, 8. differentiate between contact and non-contact force, 9. list TWO examples of contact and non- contact force, 10. Define fiction, 11. Explain laws of friction, 12. List types of friction, 13. State TWO advantages and disadvantages of friction, 14. State two uses of friction

Exercises

1. List FOUR types of motion and give ONE example of each
2. Explain the phenomenon of Brownian motion
3. Electromagnetic force is the fundamental interaction responsible for contact forces explain.
4. Differentiate between the coefficient of static friction and kinetic friction

LESSON 6 NOTE

Work, Energy and Power

Concept of Work

When we are told that a person pushes on an object with a certain force, we only know how hard the person pushes: we do not know what the pushing accomplishes. If you put energy into an object, then you do work on that object. If a first object is the agent that gives energy to a second object, then the first object does work on the second object. The energy goes from the first object into the second object. At first we will say that if an object is standing still, and you get it moving, then you have put energy into that object.

Definition of Work

It is defined as the product of the force and the distance moved in the direction of the force.

Measurement of Work:

Work is measured in units of **joules** (J), where 1 J = 1 N · m = 1 kg · m^2/s^2. That is, the SI units for work are the joule (J) or Newton-meter (N * m), from the function *W* = *F* * *s* where *W* is work, *F* is force, and *s* is the displacement. The joule is also the SI unit of energy.

In the case of a constant force, work is the scalar product of the force acting on an object and the resulting displacement of the object caused by that force. Though both force and displacement are vector quantities, work has no direction due to the nature of a scalar product (or dot product)

Work When Force and Displacement Are Parallel

When the force exerted on an object is in the same direction as the displacement of the object, calculating work is a simple matter of multiplication. Suppose you exert a force of 10 N on a box in the northward direction, and the box moves 5 m to the north. The work you have done on the box is $10\,N \times 5\,m =$

$50\ N.m = 50\ J$. If force and displacement are parallel to one another, then the work done by a force is simply the product of the magnitude of the force and the magnitude of the displacement.

Work When Force and Displacement Are Not Parallel

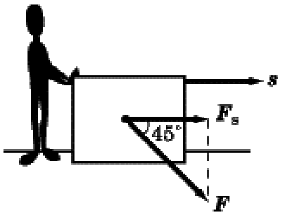


Fig 1.0

Unfortunately, matters are not quite as simple as scalar multiplication when the force and displacement vectors are not parallel. In such a case, we define work as the product of the displacement of a body and the component of the force in the direction of that displacement.

For instance, suppose you push a box with a force F along the floor for a distance ***s***, but rather than pushing it directly forward, you push on it at a downward angle of 45º as shown in fig 1.0. The work you do on the box is not equal to $F \times s,$ the magnitude of the force times the magnitude of the displacement. Rather, it is equal to $F_s \times s$, the magnitude of the force exerted in the direction of the displacement times the magnitude of the displacement.
Some simple trigonometry shows us that $F_s = F \cos\theta$, where θ is the angle between the ***F*** vector and the ***s*** vector. With this in mind, we can express a general formula for the work done by a force, which applies to all cases:

$$W = F_s \times s = Fs\cos\theta$$

This formula also applies to the cases where ***F*** and ***s*** are parallel, since in those cases. $\theta = 0$, and $\cos\theta = 1$, so

$$W = F_s.$$

Dot Product Work is the dot product of the force vector and the displacement vector. As we recall, the dot product of two vectors is the product of the magnitudes of the two vectors multiplied by the cosine of the angle between the two vectors. So the most general vector definition of work is:

$$W = F_s\,.\,s = Fs\cos\theta$$

Summary

The concept of work is actually quite straightforward, as you will see with a little practice.

If force and displacement are both in the same direction, the work done is the product of the magnitudes of force and displacement.

If force and displacement are at an angle to one another, you need to calculate the component of the force that points in the direction of the displacement or the component of the displacement those points in the direction of the force. The work done is the product of the one vector and the component of the other vector.

If force and displacement are perpendicular, no work is done.

Because of the way work is defined in physics, there are a number of cases that go against our everyday intuition. Work is not done whenever a force is exerted, and there are certain cases in which we might think that a great deal of work is being done, but in fact no work is done at all. Let us look at some examples

You do work on a 10 kg mass when you lift it off the ground (Fig. 1.1b), but you do no work to hold the same mass stationary in the air. As you strain to hold the mass in the air, you are actually making sure that it is not displaced. Consequently, the work you do to hold it is zero.

Displacement is a vector quantity that is not the same thing as distance travelled. For instance, if a weightlifter raises a dumbbell 1 m, then lowers it to its original position, the weightlifter has not done any work on the dumbbell.

When a force is perpendicular to the direction of an object's motion, this force does no work on the object. For example, say you swing a tethered ball in a circle overhead, as in Fig 1.1a. The tension force, ***T***, is always perpendicular to the velocity, ***v***, of the ball, and so the rope does no work on the ball.

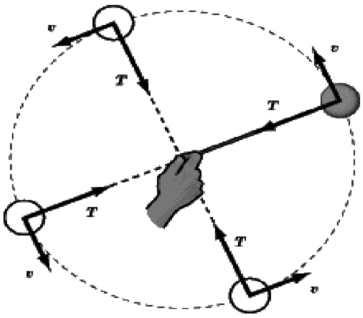


Fig 1.1a

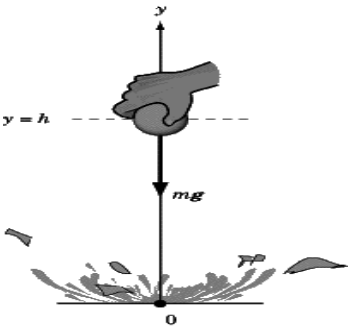
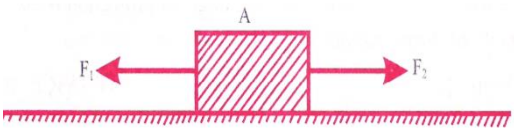


fig 1.1b

WORKED EXAMPLE



The diagram in fig 1.2 shows two forces F_1 and F_2 acting on an object, A, of mass 5kg resting on a frictionless surface, S.

(i) State the condition under which the object will remain at rest

(ii) If F_1 and F_2 are 10 N and 18 N respectively, calculate the work done when the object moves through a distance of 2m

(iii) Calculate the acceleration of the object.

(iv) An additional mass is placed on A while F_1 = F_2 remain the same. What effect will this have on the acceleration of the system?

Solution

(i) The object A remain at rest if $F_1 = F_2$

(ii) $F_1 = 10N \quad F_2 = 18N$

The resultant force is $F_1 - F_2 = 18 - 10 = 8N$ in the direction of the F_2

Work done =Resultant force x distance moved

$W = F.S = 8 \times 2 = 16J$

(iii) From Newton's second law of motion

Resultant force $F = m \times a,\ a = \frac{F}{m} = \frac{8}{5} = 1.6ms^{-2}$

(iv) if an additional load is placed on A, the total mass will increase. If the resultant force remains the same, the acceleration will reduce

Work Problems with Graphs

Interpretation a graph is a sure way of testing once understanding of work . This graph will is a graph of force vs. position or a graph of $F\cos\theta$ vs. position. *The work done in a force vs. displacement graph is equal to the area between the graph and the x-axis during the same interval.*

EXAMPLE

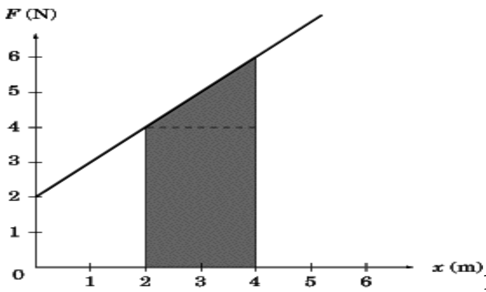


fig. 1.2

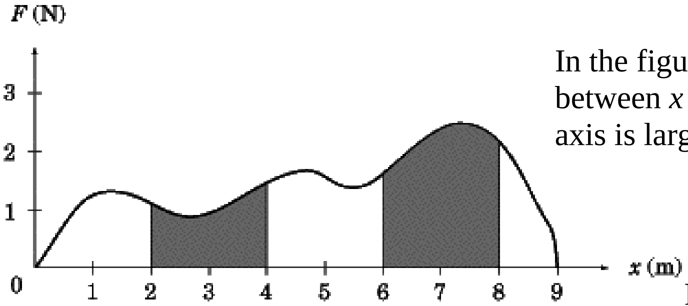
Solution:

The work done on the box is equal to the area of the shaded region in fig. 1.4 above, or the area of a rectangle of width 2 and height 4 plus the area of a right triangle of base 2 and height 2. Determining the amount of work done is simply a matter of calculating the area of the rectangle and the area of the triangle.

The graph above plots the force exerted on a box against the displacement of the box. What is the work done by the force in moving the box from $x = 2$ to $x = 4$?

$$2 \cdot 4 + \frac{1}{2} \cdot 2 \cdot 2 = 10\ \mathrm{J}$$

Curved Force vs. Position Graphs



In the figure below, more work was done between $x = 6$ and $x = 8$ than between $x = 2$ and $x = 4$, because the area between the graph and the x-axis is larger for the interval between $x = 6$ and $x = 8$.

Fig 1.3

Concept of Energy

Energy is one of the central concepts of physics, and one of the most difficult to define. One of the reasons we have such a hard time defining it is because it appears in so many different forms. There is the **kinetic** and **potential energy** of kinematic motion, the **thermal energy** of heat reactions, the chemical energy of your Discman batteries, the **mechanical energy** of a machine, the elastic energy that helps you launch rubber bands, the **electrical energy** that keeps most appliances on this planet running, and even **mass energy**, the strange phenomenon that Einstein discovered and that has been put to such devastating effect in the atomic bomb. This is only a cursory list: energy takes on an even wider variety of forms.

Definition of Energy:

Energy is defined the ability to do work, like work, is measured in joules (J). In fact, work is a measure of the transfer of energy.

Forms / Types of energy

Mechanical Energy

Mechanical energy is the energy that is possessed by an object due to its motion or due to its position. Mechanical energy can be either kinetic energy (energy of motion) or potential energy (stored energy of position). Objects have mechanical energy if they are in motion and/or if they are at some position relative to a *zero potential energy position* for examples:

- a brick held at a vertical position above the ground or zero height position).
- A moving car possesses mechanical energy due to its motion (kinetic energy).
- A moving baseball possesses mechanical energy due to both its high speed (kinetic energy) and its vertical position above the ground (gravitational potential energy).
- A World Civilization book at rest on the top shelf of a locker possesses mechanical energy due to its vertical position above the ground (gravitational potential energy).
- A barbell lifted high above a weightlifter's head possesses mechanical energy due to its vertical position above the ground (gravitational potential energy).
- A drawn bow possesses mechanical energy due to its stretched position (elastic potential energy).

Kinetic Energy

Kinetic energy is the energy a body in motion has by virtue of its motion. We define energy as the capacity to do work, and a body in motion is able to use its motion to do work. For instance, a cue ball on a pool table can use its motion to do work on the eight ball. When the cue ball strikes the eight ball, the cue ball comes to a stop and the eight ball starts moving. This occurs because the cue ball's kinetic energy has been transferred to the eight ball.

Forms of Kinetic Energy

There are many types of kinetic energy; including vibrational, translational, and rotational energies. **Kinetic energy** is the energy or capacity to do work possessed by a body because of its motion. An object that has motion - whether it is vertical or horizontal motion - has kinetic energy.

Vibrational kinetic energy is the energy due to vibrational motion, rotational kinetic energy is the energy due to rotational motion, and translational kinetic energy is the energy due to motion from one location to another). To keep matters simple, we will focus upon translational kinetic energy.

Translational kinetic energy is the energy of a particle moving in space and is defined in terms of the particle's mass, *m*, and velocity, *v*:

The amount of translational kinetic energy that an object has depends upon two variables: the mass (m) of the object and the speed (v) of the object. The following equation is used to represent the kinetic energy (KE) of an object. $KE = \frac{1}{2}mv^2$

For instance, What is the kinetic energy of a cue ball of mass 0.5 kg moving at a velocity of 2 m/s

$$KE = \frac{1}{2}(0.5kg)\left(\frac{2m}{s}\right)^2 = 1 \text{ J.}$$

Potential Energy

Potential energy, *U*, is defined as the energy possessed by a body or object by the virtue of its position in space. It is a measure of an object's unrealized

potential to have work done on it, and is associated with that object's position in space, or its configuration in relation to other objects.

Any work done on an object converts its potential energy into kinetic energy, so the net work done on a given object is equal to the negative change in its potential energy: $W = -\Delta U$

Be very respectful of the minus sign in this equation. It may be tempting to think that the work done on an object increases its potential energy, but the opposite is true. Work converts potential energy into other forms of energy, usually kinetic energy. Remove the minus sign from the equation above, and you are in direct violation of the law of conservation of energy!

Forms of potential Energy

There are many forms of potential energy, each of which is associated with a different type of force; gravitational potential energy and the potential energy of a compressed spring.

Gravitational Potential Energy

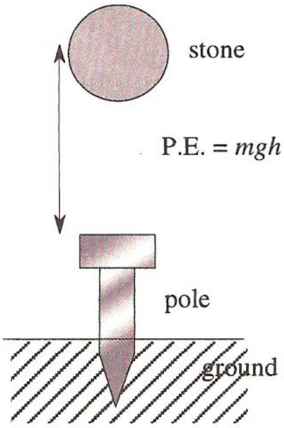


Fig 1.4

Gravitational potential energy is the energy stored in an object as the result of its vertical position or height against force of gravity. The energy is stored as the result of the gravitational attraction of the Earth for the object. The gravitational potential energy of the massive ball of a demolition machine is dependent on two variables - the mass of the ball and the height to which it is raised. These relationships are expressed by the following equation:

PE_{grav} = mass • g • height

PE_{grav} = m *• g • h

In the above equation, **m** represents the mass of the object, **h** represents the height of the object and **g** represents the gravitational field strength (9.8 N/kg on Earth) - sometimes referred to as the acceleration of gravity.
Gravitational potential energy registers the potential for work done on an object by the force of gravity.

For example, say that you lift a water balloon to height *h* above the ground. The work done by the force of gravity as you lift the water balloon is the force of gravity, *–mg*, times the water balloon's displacement, *h*. So the work done by the force of gravity is $W = mgh$Note that there is a negative amount of work done, since the water balloon is being lifted upward, in the opposite direction of the force of gravity.
By doing *–mgh* joules of work on the water balloon, you have increased its gravitational potential energy by *mgh* joules (recall the equation $= -\Delta U$). In other words, you have increased its potential to accelerate downward and cause a huge splash. Because the force of gravity has the potential to do *mgh* joules of work on the water balloon at height *h*, we say that the water balloon has *mgh* joules of gravitational potential energy.

$$U_g = mgh$$

For instance, a 50 kg mass held at a height of 4 m from the ground has a gravitational potential energy of:

$$U_g = mgh = (50kg)\left(\frac{9.8m}{m^2}\right)(4m) = 1960\,J$$

The most important thing to remember is that *the higher an object is off the ground, the greater its gravitational potential energy.*

Elastic Potential Energy

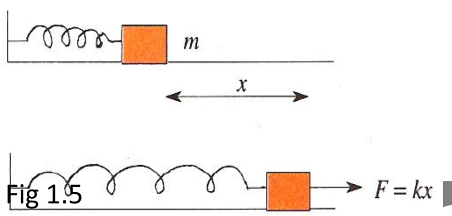


Fig 1.5

Elastic potential energy is the energy stored in elastic materials as the result of their stretching or compressing. Elastic potential energy can be stored in rubber bands, bungee cords, trampolines, springs, an arrow drawn into a bow, etc. The amount of elastic potential energy stored in such a device is related to the amount of stretch of the device - the more stretch, the more stored energy.

Springs are a special instance of a device that can store elastic potential energy due to either compression or stretching.

A force is required to compress a spring; the more compression there is, the more force that is required to compress it further. For certain springs, the amount of force is directly proportional to the amount of stretch or compression (x); the constant of proportionality is known as the spring constant (k). $F_{spring} = K \times x$

Such springs are said to follow Hooke's Law. If a spring is not stretched or compressed, then there is no elastic potential energy stored in it. There is a special equation for springs that relates the amount of elastic potential energy to the amount of stretch (or compression) and the spring constant. The equation is

$$PE_{spring} = \frac{1}{2} * K * X^2$$

Where K = spring constant, X = amount of compression (relative equilibrium)

To summarize, potential energy is the energy that is stored in an object due to its position relative to some zero position. An object possesses gravitational potential energy if it is positioned at a height above (or below) the zero height. An object possesses elastic potential energy if it is at a position on an elastic medium other than the equilibrium position.

Worked Examples:

A student drops an object of mass 10 kg from a height of 5 m. What is velocity of the object when it hits the ground? Assume, g = -10 m/s^2

Before the object is released, it has a certain amount of gravitational potential energy, but no kinetic energy. When it hits the ground, it has no gravitational potential energy, since $h = 0$, but it has a certain amount of kinetic energy. The mechanical energy, E, of the object remains constant, however. That means that the potential energy of the object before it is released is equal to the kinetic energy of the object when it hits the ground.

When the object is dropped, it has a gravitational potential energy of:

$$mgh = (10\ \mathrm{kg})(-10\ \mathrm{m/s^2})(-5\ \mathrm{m}) = 500\ \mathrm{J}$$

By the time it hits the ground, all this potential energy will have been converted to kinetic energy. Now we just need to solve for v:

$$\frac{1}{2}mv^2 = 500\ \mathrm{J}$$

$$v^2 = \frac{2(500\ \mathrm{J})}{10\ \mathrm{kg}} = (100\ \mathrm{m/s})^2$$

Conservation of Mechanical Energy

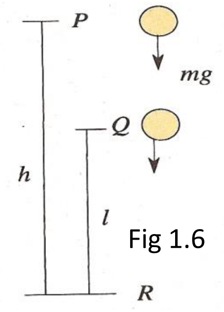


Fig 1.6

The principle of conservation of Mechanical energy tells us that the energy in the closed system or isolated is constant or conserved. It states that energy cannot be created nor destroyed but can be changed from one form to another form.

This law applies to any closed system that is, frictionless system. A closed system is a system where no energy leaves the system and goes into the outside world, and no energy from the outside world enters the system.

It is virtually impossible to create a truly closed system on Earth, since energy is almost always dissipated through friction, heat, or sound, but we can create close approximations. The conservation of mechanical energy only applies to closed systems.

Energy transformation from one form to another

Energy can be transferred via a force, or as heat. For instance, let's return to the example mentioned earlier of the box hanging by a string. As it hangs motionless, it has gravitational potential energy, a kind of latent energy. When we cut the string, that energy is converted into **kinetic energy**, or work, as the force of gravity acts to pull the box downward. When the box hits the ground, that kinetic energy does not simply disappear. Rather, it is converted into sound and heat energy: the box makes a loud noise and the impact between the ground and the box generates a bit of heat.

We now have equations relating work to both kinetic and potential energy:

$$W = \Delta KE$$

$$W = -\Delta U$$

Combining these two equations gives us this important result:

$$\Delta KE + \Delta U = 0$$

Or, alternatively,

$$\Delta KE = -\Delta U$$

As the kinetic energy of a system increases, its potential energy decreases by the same amount, and vice versa. As a result, the sum of the kinetic energy and the potential energy in a system is constant. We define this constant as E, the mechanical energy of the system:

$$KE + U = E$$

The Work-Energy Theorem or Energy Principle (Interchange ability of work and energy)
If you recall, work is a measure of the transfer of energy. An object that has a certain amount of work done on it has that amount of energy transferred to it. This energy moves the object over a certain distance with a certain force; in other words, it is kinetic energy. For example, a golfer uses a club and gets a stationary golf ball moving when he
or she hits the ball. The club does work on the golf ball as it strikes the ball. Energy leaves the club and enters the ball. This is a transfer of energy. Thus, we say that the club did work on the ball. And, before the ball was struck, the golfer did work on the club. The club was initially standing still, and the golfer got it moving when he or she swung the club

This handy little fact is expressed in the **work-energy theorem** or energy principle

Work-energy theorem states that the net work done on an object is equal to the object's change in kinetic energy or The change in the kinetic energy of an object is equal to the net work done on the object.

$$W = \Delta KE$$

$$W_{net} = \frac{1}{2}mv_{final}^2 - \frac{1}{2}\mathrm{mv}_{\mathrm{initial}}^2$$

This fact is referred to as the Work-Energy Theorem or Principle

EXAMPLE

A hockey of mass 1 kg slides across the ice with an initial velocity of 10 m/s. There is a 1 N force of friction acting against the punck. What is the puck's velocity after it has glided 32 m along the ice?

Solution:

First, let's determine the initial kinetic energy of the puck.

$$KE = \frac{1}{2}mv^2 = \frac{1}{2}(1kg)(10m/s)^2 = 50 \text{ J}$$

The friction between the puck and the ice decelerates the puck. The amount of work the ice does on the puck, which is the product of the force of friction and the puck's displacement, is negative.

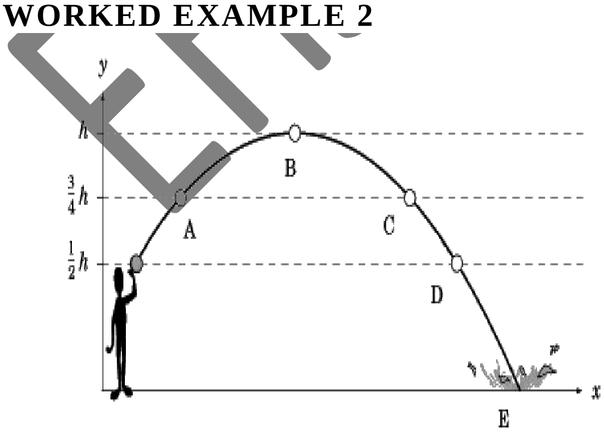
$$W = F.s = (-1\,N)(32\,m) = 32 \text{ J}$$

The work done on the puck decreases its kinetic energy, so after it has glided 32 m, the kinetic energy of the puck is 50 – 32 = 18 J. Now that we know the final kinetic energy of the puck, we can calculate its final velocity by once more plugging numbers into the formula for kinetic energy:

$$KE = \frac{1}{2}mv^2 \quad 18J = \frac{1}{2}(1kg)v^2$$

$$v^2 = \left(\frac{36m}{s}\right)^2 \quad v = 6m/s$$

WORKED EXAMPLE 2



Consider the above diagram of the trajectory of a thrown tomato

1. At what point is the potential energy greatest?
2. At what point is kinetic energy the least?
3. At what point is kinetic energy greatest?

At what point is kinetic energy decreasing and potential energy increasing?
At what point are kinetic energy and potential equal to the values at position A?

The answer to question 1 is point B. At the top of the tomato's trajectory, the tomato is the greatest distance above the ground and hence has the greatest potential energy.
The answer to question 2 is point B. At the top of the tomato's trajectory, the tomato has the smallest velocity, since the *y*-component of the velocity is zero, and hence the least kinetic energy. Additionally, since mechanical energy is conserved in projectile motion, we know that the point where the potential energy is the greatest corresponds to the point where the kinetic energy is smallest.
The answer to question 3 is point E. At the bottom of its trajectory, the tomato has the greatest velocity and thus the greatest kinetic energy.
The answer to question 4 is point A. At this point, the velocity is decreasing in magnitude and the tomato is getting higher in the air. Thus, the kinetic energy is decreasing and the potential energy is increasing.
The answer to question 5 is point C. From our study of kinematics, we know that the speed of a projectile is equal at the same height in the projectile's ascent and descent. Therefore, the tomato has the same kinetic energy at points A and C. Additionally, since the tomato has the same height at thesepoints, its potential energy is the same at points A and C.

Renewable and Non-renewable Energy

Renewable energy sources are sources of energy which are replenished naturally and over relatively short periods of time. Examples include: solar energy, energy from wind, geothermal energy, energy from biomass etc.

Non-renewable energy sources are sources of energy that are available in limited supplies usually due to the long time it takes for them to be replenished. Examples include: coal, nuclear energy, oil and natural gas etc.

Power

Mechanical systems, such as engines, are not limited by the amount of work they can do, but rather by the rate at which they can perform the work. In physics, **power** is the rate at which work is performed or energy is converted. As a simple example, burning a kilogram of coal releases much more energy than does detonating a kilogram of TNT but because the TNT reaction releases energy much more quickly, it delivers far more power than the coal

Definition of Power

Power, *P*, is defined as the rate at which work is done, or the rate at which energy is transformed. Power can also be defined as the product of a force times the velocity of its point of application, in which case work is the integral of power along the trajectory of the point of application of the force
The formula for average power is:

$$\frac{\Delta W}{\Delta t} \text{ or } \frac{\Delta E}{\Delta t}$$

Power is measured in units of watts (W), where 1 W = 1 J/s.

WORKED EXAMPLE3

> A piano mover pushes on a piano with a force of 100 N, moving it 9 m in 12 s. With how much power does the piano mover push?

Power is a measure of the amount of work done in a given time period. First we need to calculate how much work the piano mover does, and then we divide that quantity by the amount of time the work takes.

$$W = Fs = (100\ \mathrm{N})(9\ \mathrm{m}) = 900\ \mathrm{J}$$

$$P = \frac{\Delta W}{\Delta t} = \frac{900\ \mathrm{J}}{12\ \mathrm{s}} = 75\ \mathrm{W}$$

Be careful not to confuse the symbol for watts, W, with the symbol for work, *W*.

Average Power

If ΔW is the amount of work performed during a period of time of duration Δt, the **average power** P_{avg} over that period is given by the formula $\boldsymbol{P_{ave} = \frac{\Delta W}{\Delta t}}$

It is the average amount of work done or energy converted per unit of time. The average power is often simply called "power" when the context makes it clear.

Instantaneous Power

The **instantaneous power** is then the limiting value of the average power as the time interval Δt approaches zero.

*The expression for power is work/time, and since the expression for work is force*displacement, the expression for power can be rewritten as (force*displacement)/time. Since the expression for velocity is displacement/time, the expression for power can be rewritten once more as force*velocity. This is shown below.*

$$Power = \frac{Work}{Time} = \frac{Force\,.Displacement}{Time} = \frac{\Delta W}{\Delta t} \qquad Power = Force.\frac{Displacement}{Time} = F.\frac{\Delta s}{\Delta t}$$

$$Power = Force * Velocity = F.v$$

Units

The dimension of power is energy divided by time. The SI unit of power is the watt (W), which is equal to one joule per second. Other units of power include ergs per second (erg/s), horsepower (hp), metric horsepower

Mechanical power

In mechanics, the work done on an object is related to the forces acting on it by

$$W = F \cdot \Delta d$$

Where is force Δd is the displacement of the object.

In systems with fluid flow, power is related to pressure, p and volumetric flow rate, Q:

$$P = p \cdot Q$$

Where p is pressure (in pascals, or N/m^2 in SI units) Q is volumetric flow rate (in m^3/s in SI units)

Electrical power

The instantaneous electrical power P delivered to a component is given by

$$P(t) = I(t) \cdot V(t)$$

Where $P(t)$ is the instantaneous power, measured in watts (joules per second)

$V(t)$ is the potential difference (or voltage drop) across the component, measured in volts

$I(t)$ is the current through it, measured in amperes

If the component is a resistor with time-invariant voltage to current ratio, then:

$$P = I^2 \cdot R = \frac{V^2}{R}$$

where

$$R = V/I$$

R is the resistance, measured in ohms

Examples will be solved in class, after which assignment will be given

LESSON 7 NOTE

Mechanical Energy

Simple Machine

Everyone uses some machines every day. Some are simple tools, such as bottle opener and screwdrivers; other are complex, such as bicycle and automobile. Machines, whether powered by engineers or people, makes takes easier. A machine ease the load by changing either the magnitude or the direction of a force as it transmit energy to the task.

Terms used in machine

Mechanical Advantage (M.A) is the ratio of resistance (Load) force to the effort force

M.A = $\frac{Load}{Effort} = \frac{F_R}{F_E}$

Many machines such as the bottle opener, have a mechanical advantage greater than one. When the M.A is greater than one, the machine increase the force you apply.

Velocity Ratio (V.R) is the ratio of the distance moved by effort to the distance moved by load in the same time interval.

V.R = $\frac{Distance\ moved\ by\ effort}{Distance\ moved\ by\ load}$

Pivot is the point about which turning effect occurs in the machine.

Load is the force overcome by an effort

Effort is the force applied to the machine

Efficiency is the ratio of work/ energy output to work/energy input expressed in percentage.

The teacher will solve for the efficiency of a machine in class.

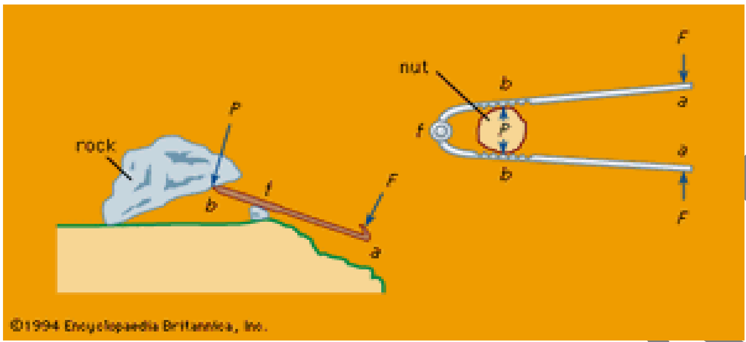
Note: efficiency in a real machines, not all of the input work is available as output work. Some of the energy transferred by the work may be lost to thermal energy/friction.

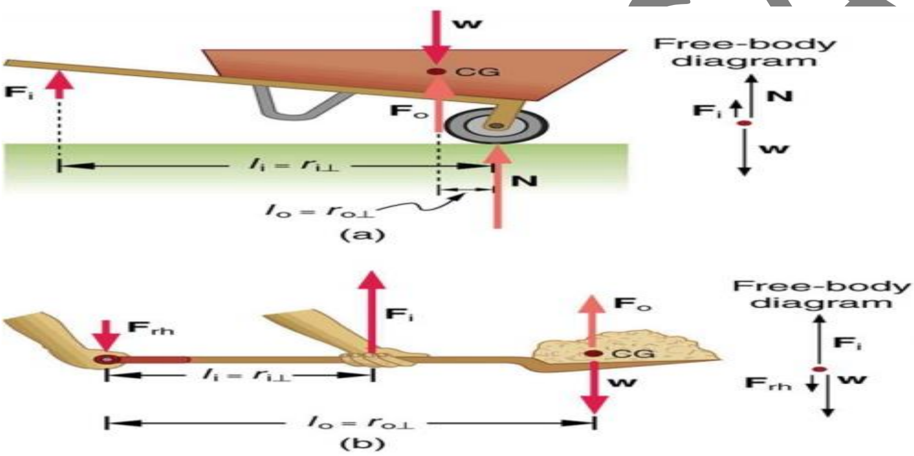
An ideal machine has equal output and input work, and the efficiency is 100%. All real machines have efficiency less than 100% due to energy lost to thermal/ friction.

Types of machines with their velocity ratio

1. Lever

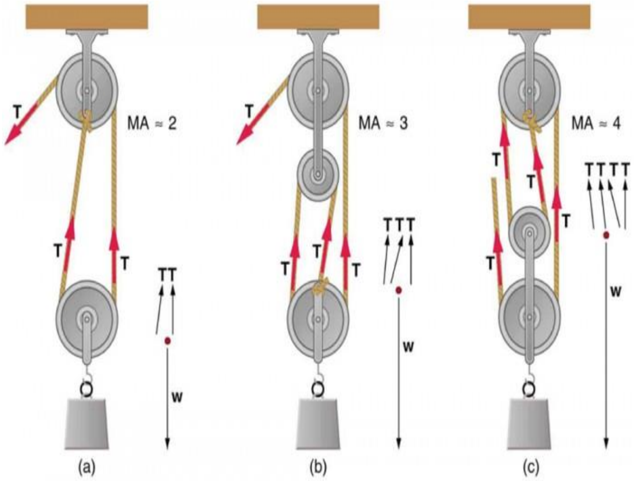
- Two examples of levers(Left) A crowbar, supported and turning freely on a fulcrum *f*, multiplies a downward force *F* applied at point *a* such that it can overcome the load *P* exerted by the mass of the rock at point *b*. If, for example, the length *af* is five times *bf*, the force *F* will be multiplied five times. (Right) A nutcracker is essentially two levers connected by a pin joint at a fulcrum *f*. If *af* is three times *bf*, the force *F* exerted by hand at point *a* will be multiplied three times at *b*, easily overcoming the compressive strength *P* of the nutshell.
- A lever is a bar or board that rests on a support called a fulcrum. A downward force exerted on one end of the lever can be transferred and increased in an upward direction at the other end, allowing a small force to lift a heavy weight.

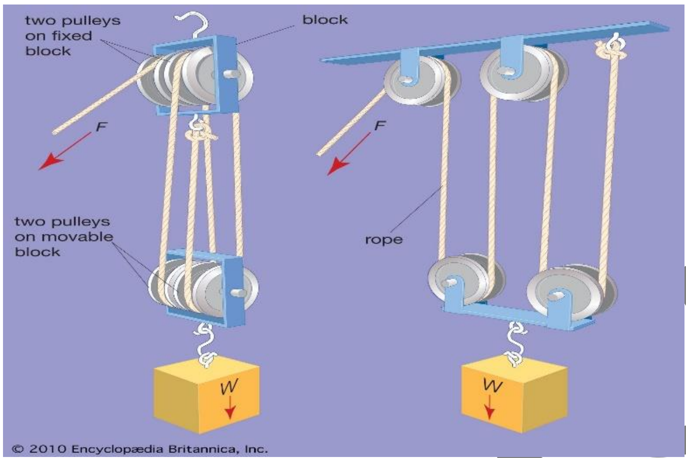




2. PULLEY

A pulley is a [wheel]() that carries a flexible rope, cord, cable, chain, or belt on its rim. Pulleys are used singly or in combination to [transmit]() [energy]() and motion. Pulleys with grooved rims are called sheaves. In [belt drive](), pulleys are affixed to shafts at their axes, and power is transmitted between the shafts by means of endless belts running over the pulleys.





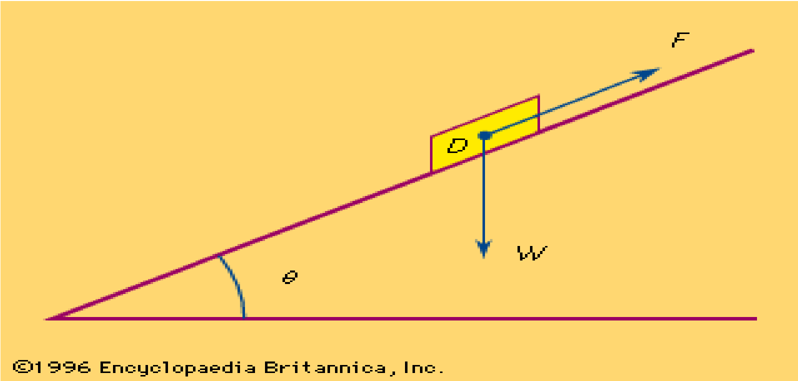
Block and tackle

One or more independently rotating pulleys can be used to gain mechanical advantage, especially for lifting weights. The shafts about which the pulleys turn may affix them to frames or blocks, and a combination of pulleys, blocks, and rope or other flexible material is referred to as a block and tackle. The Greek mathematician Archimedes (3rd century bce) is reported to have used compound pulleys to pull a ship onto dry land.

The velocity ratio of a pulley is = the number of pulleys

3. INCLINED PLANE

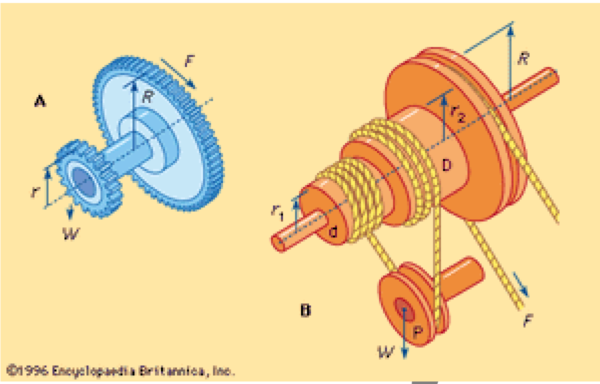
An inclined plane consists of a sloping surface; it is used for raising heavy bodies. The plane offers a mechanical advantage in that the force required to move an object up the incline is less than the weight being raised (discounting friction). The steeper the slope, or incline, the more nearly the required force approaches the actual weight. Expressed mathematically, the force F required to move a block D up an inclined plane without friction is equal to its weight W times the sine of the angle the inclined plane makes with the horizontal (θ). The equation is $F = W \sin \theta$.



The velocity ratio = $\frac{1}{\sin\theta}$

4. **The [wheel and axle]**

A wheel and axle is made up of a circular frame (the wheel) that revolves on a shaft or rod (the axle). In its earliest form it was probably used for raising weights or water buckets from wells.



wheel and axle arrangements

Two wheel and axle arrangements (A) With a large gear and a small gear attached to the same shaft, or axle, a force *F* applied at the radius *R* on the large gear is sufficient to overcome the larger force *W* at the radius *r* on the small gear, turning the axle. (B) In a drum and rope arrangement capable of raising weights, a large drum of radius *R* can be used to turn a small drum. An increase in mechanical advantage can be obtained by using the large drum to turn a small drum with two radii as well as a pulley block. When a force *F* is applied to the rope wrapped around the large drum, the rope wrapped around the small two-radius drum winds off of d (radius r_1) and onto D (radius r_2). The force *W* on the radius of the pulley block P is easily overcome, and the attached weight is lifted.

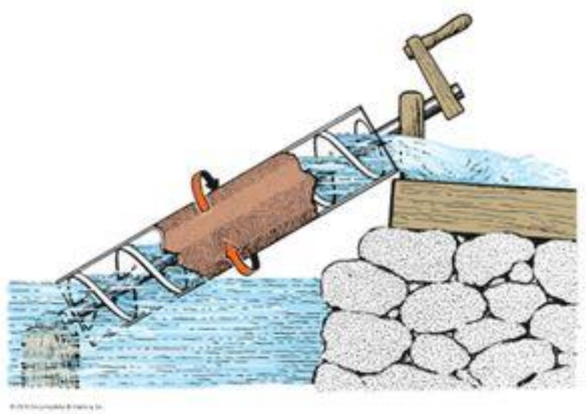
Its principle of operation is best explained by way of a device with a large gear and a small gear attached to the same shaft. The tendency of a force, *F*, applied at the radius *R* on the large gear to turn the shaft is sufficient to overcome the larger force *W* at the radius *r* on the small gear. The force amplification, or mechanical advantage, is equal to the ratio of the two forces (*W*:*F*) and also equal to the ratio of the radii of the two gears (*R*:*r*).

If the large and small gears are replaced with large- and small-diameter drums that are wrapped with ropes, the wheel and axle becomes capable of raising weights. The weight being lifted is attached to the rope on the small drum, and the operator pulls the rope on the large drum. In this arrangement the mechanical advantage is the radius of the large drum divided by the radius of the small drum. An increase in the mechanical advantage can be obtained by using a small drum with two radii, r_1 and r_2, and a pulley block. When a force is applied to the large drum, the rope on the small drum winds onto D and off of d.

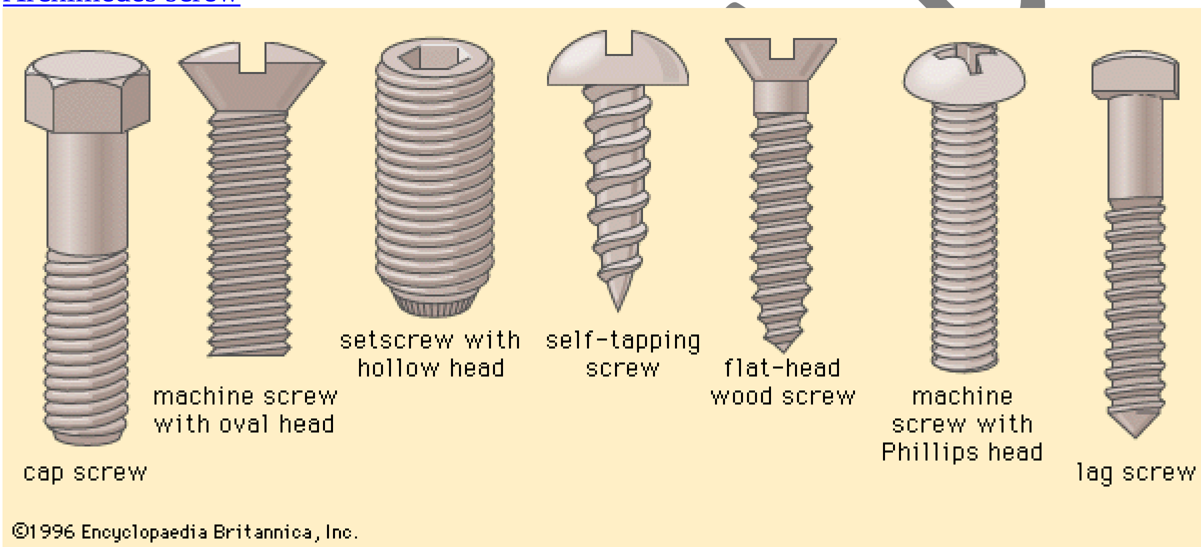
The velocity ratio = $\frac{Radius\ of\ wheel}{Radius\ of\ axle} = \frac{R}{r}$

5. **The screw**

A screw is a usually circular cylindrical member with a continuous helical rib, used either as a fastener or as a force and motion modifier.



Archimedes screw



Although the Pythagorean philosopher Archytas of Tarentum (5th century bce) is the alleged inventor of the screw, the exact period of its first appearance as a useful mechanical device is obscure. The invention of the water screw is usually ascribed to Archimedes, but evidence exists of a similar device used for irrigation in Egypt at an earlier date. The screw press, probably invented in Greece in the 1st or 2nd century bce, has been used since the days of the Roman Empire for pressing clothes. In the 1st century ce, wooden screws were used in wine and olive-oil presses, and cutters (taps) for cutting internal threads were in use.

Screws and screw heads

Screws and screw heads (A) Cap screw, (B) machine screw with oval head, (C) setscrew with hollow head, (D) self-tapping screw, (E) flat-head wood screw, (F) machine screw with Phillips head, (G) lag screw.

Cap and machine screws are used to clamp machine parts together, either when one of the parts has a threaded hole or in conjunction with a nut. These screws stretch when tightened, and the tensile load created clamps the parts together. The setscrew fits into a threaded hole in one member; when tightened, the cup-shaped point is pressed into a mating member (usually a shaft) and prevents relative motion. Self-tapping screws form or cut mating threads by displacing material adjacent to a pilot hole so that it flows around the screw.

The velocity ratio = $\frac{2\pi r}{P}$

r = radius of the screw
p = length of pitch or differential length

6. The wedge

A wedge is an object that tapers to a thin edge. Pushing the wedge in one direction creates a force in a sideways direction. It is usually made of metal or wood and is used for splitting, lifting, or tightening, as in securing a hammer head onto its handle.

The wedge was used in prehistoric times to split logs and rocks; an ax is also a wedge, as are the teeth on a saw. In terms of its mechanical function, the screw may be thought of as a wedge wrapped around a cylinder.

Examples will be solved in class, after which assignment will be given