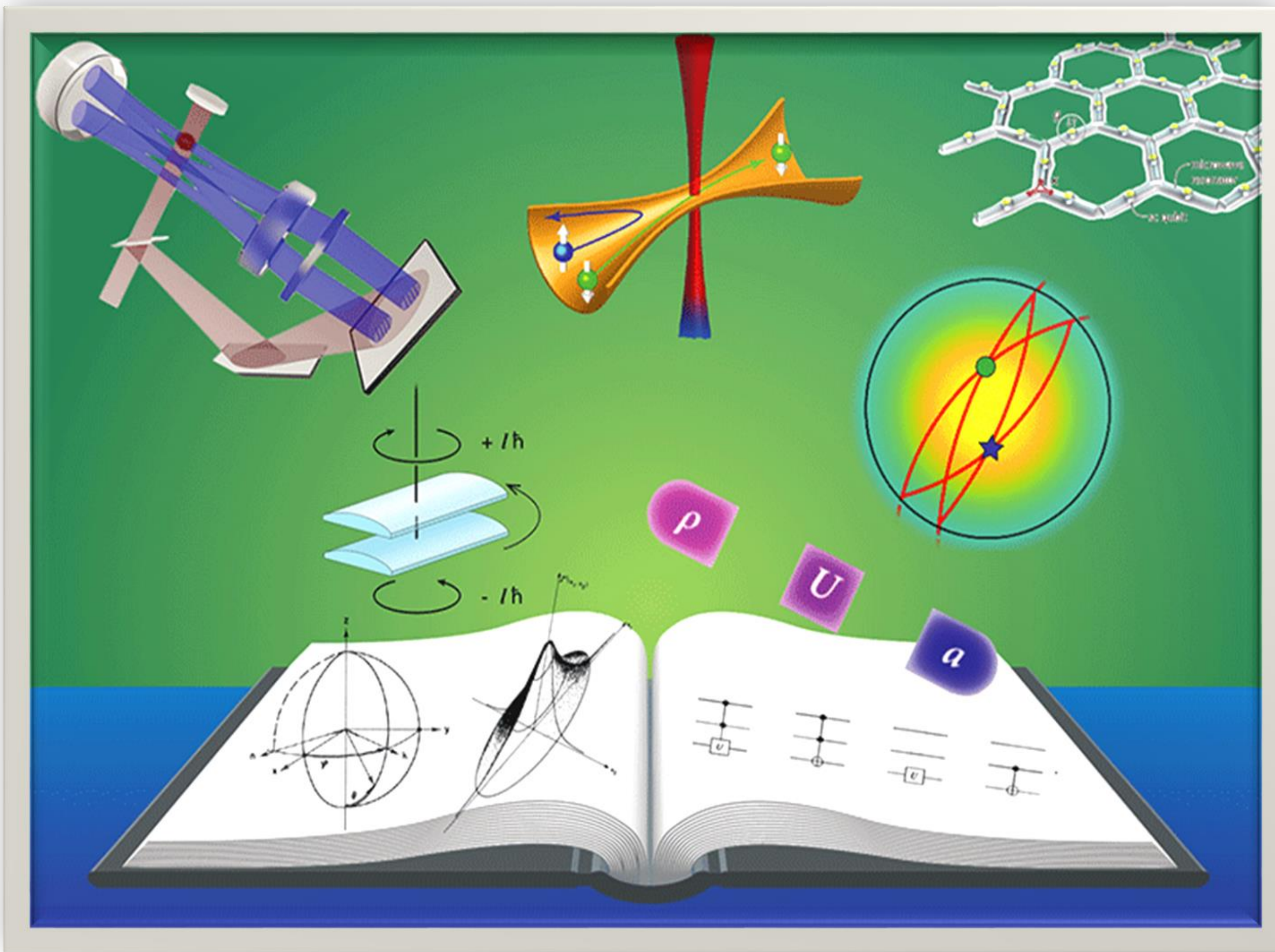
Physics

XI



Resource material of Ziauddin board

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BENCHMARKS

- Ask questions that can be investigated empirically.
- Develop solutions to problems through reasoning, observation, and investigations.
- Design and conduct scientific investigations.
- Recognize and explain the limitations of measuring devices.
- Gather and synthesize information from books and other sources of information.
- Discuss topics in groups by making clear presentations, restating or summarizing what others have said, asking for clarification or elaboration, taking alternative perspectives, and defending a position.
- Justify plans or explanations on a theoretical or empirical basis.
- Describe some general limitations of scientific knowledge.
- Show how common themes of science, mathematics, and technology apply in real world contexts.
- Discuss the historical development of the key scientific concepts and principles.
- Explain the social and economical advantages and risks of new technology.
- Develop an awareness and sensitivity to the natural world.
- Describe the historical, political and social factors affecting developments in science.
- Appreciate the ways in which models, theories and laws in physics have been tested and validated
- Assess the impacts of applications of physics on society and the environment.
- Justify the appropriateness of a particular investigation plan.
- Identify ways in which accuracy and reliability could be improved in investigations.
- Use terminology and report styles appropriately and successfully to communicate information.
- Assess the validity of conclusions from gathered data and information.
- Explain events in terms of Newton's laws and law of conservation of momentum
- Explain the effects of energy transfers and energy transformations.
- Explain mechanical, electrical and magnetic properties of solids and their significance.
- Demonstrate an understanding of the principles related to fluid dynamics and their applications.
- Explain that heat flow and work are two forms of energy transfers between systems and their significance.
- Understand wave properties, analyze wave interactions and explain the effects of those interactions.
- Demonstrate an understanding of wave model of light as e.m waves and describe how it explains diffraction patterns, interference and polarization.

CHAPTER CONTENT

Unit - 01

Measurement

Topic	Understandings	Skills
The scope of Physics • SI base, supplementary and derived units • Errors and uncertainties • Use of significant figures • Precision and accuracy • Dimensionality	• describe the scope of Physics in science, technology and society. • state SI base units, derived units, and supplementary units for various Measurements. • express derived units as products or quotients of the base units. • State the conventions for indicating units as set out in the SI units. • explain why all measurements contain some uncertainty. • distinguish between systematic errors (including zero errors) and random errors. • identify that least count or resolution of a measuring instrument is the smallest Increment measurable by it. • differentiate between precision and accuracy. • assess the uncertainty in a derived quantity by simple addition of actual, fractional or Percentage uncertainties. • quote answers with correct scientific notation, number of significant figures and units in all numerical and practical work.	• measure, using appropriate techniques, the length, mass, time, temperature and electrical quantities by making use of both analogue scales and digital displays • Particularly short time interval by ticker timer and by C.R.O. • measure length and diameter of a solid cylinder and hence estimate its volume • Quoting proper number of significant figures. • measure the diameters of a few ball bearings of different sizes and estimate their • Volumes. Mention the uncertainty in each result. • analyze and evaluate the above experiment and suggest improvements. • determine the radius of curvature of a convex lens and concave lens using a • Speedometer.

Unit overview

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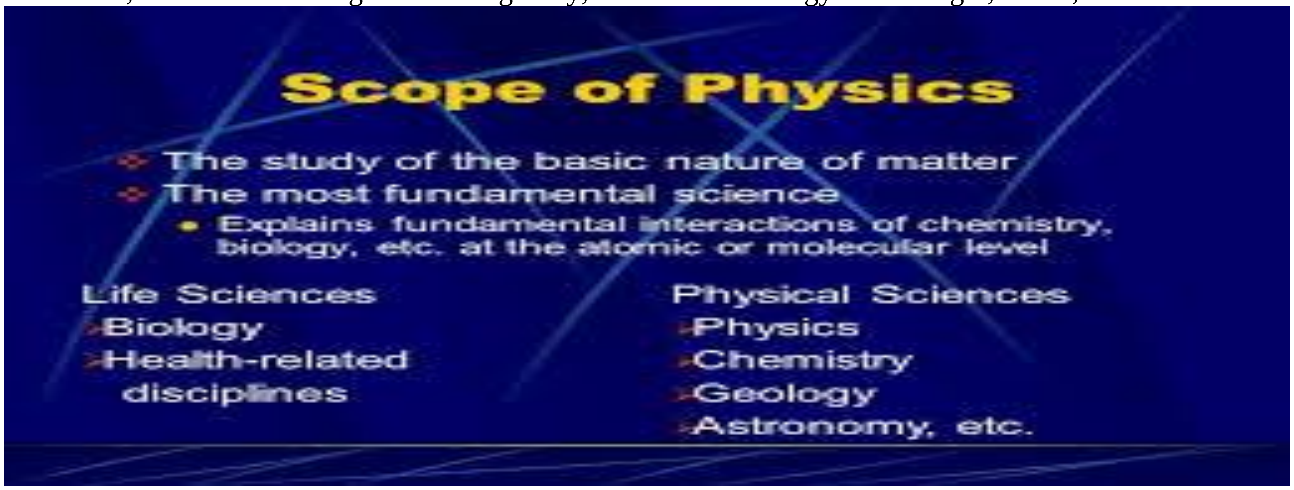
1)The Scope of Physics

Introduction to Physics:

Physics is the study of energy, matter, and their interactions. It's a very broad field because it is concerned with matter and energy at all levels—from the most fundamental particles of matter to the entire universe. Some people would even argue that physics is the study of everything! Important concepts in physics include motion, forces such as magnetism and gravity, and forms of energy such as light, sound, and electrical energy.



2)**SI base, supplementary and derived units**

SI derived units are units of measurement derived from the seven base units specified by the International System of Units (SI). They are either dimensionless or can be expressed as a product of one or more of the base units, possibly scaled by an appropriate power of exponentiation.

The SI has special names for 22 of these derived units (for example, hertz, the SI unit of measurement of frequency), but the rest merely reflect their derivation: for example, the square metre (m2), the SI derived unit of area; and the kilogram per cubic metre (kg/m3 or kg·m−3), the SI derived unit of density.

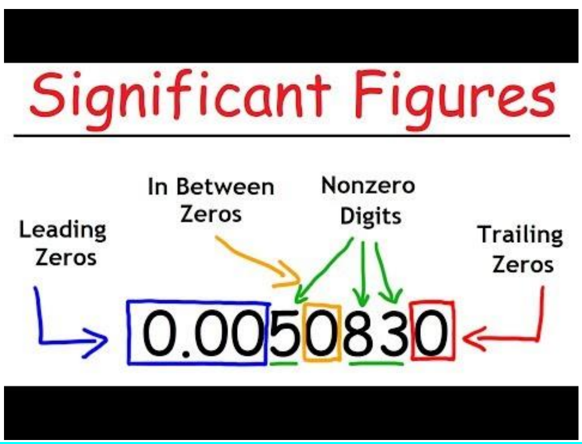
The names of SI derived units, when written in full, are always in lowercase. However, the symbols for units named after persons are written with an uppercase initial letter. For example, the symbol for hertz is "Hz", but the symbol for metre is "m".

SI derived units with names

Formed by combining
- Base
- Supplementary or
- Other derived units

Quantity	SI Unit Symbol	Name	Base Units
Frequency	Hz	hertz	s^{-1}
Force	N	newton	$kg \cdot m \cdot s^{-2}$
Pressure or stress	Pa	pascal	$kg \cdot m^{-1} \cdot s^{-2}$
Energy or work	J	joule	$kg \cdot m^2 \cdot s^{-2}$
Quantity of heat	J	joule	$kg \cdot m^2 \cdot s^{-2}$
Power radiant flux	W	watt	$kg \cdot m^2 \cdot s^{-3}$
Electric charge	C	coulomb	$A \cdot s$
Electric potential	V	volt	$kg \cdot m^2 \cdot s^{-3} \cdot A^{-1}$
Potential difference	V	volt	$kg \cdot m^2 \cdot s^{-3} \cdot A^{-1}$
Electromotive force	V	volt	$kg \cdot m^2 \cdot s^{-3} \cdot A^{-1}$
Capacitance	F	farad	$A^2 \cdot s^4 \cdot kg^{-1} \cdot m^{-2}$
Electric resistance	Ω	ohm	$kg \cdot m^2 \cdot s^{-3} \cdot A^{-2}$
Conductance	S	siemens	$kg^{-1} \cdot m^{-2} \cdot s^3 \cdot A^2$
Magnetic flux	Wb	weber	$m^2 \cdot kg \cdot s^{-2} \cdot A^{-1}$
Magnetic flux density	T	tesla	$kg \cdot s^{-2} \cdot A^{-1}$
Inductance	H	henry	$kg \cdot m^2 \cdot s^{-2} \cdot A^{-2}$
Luminous flux	lm	lumen	cd
Illuminance	lx	lux	$cd \cdot m^{-2}$
Celsius temperature*	°C	degree Celsius	K
Activity (radionuclides)	Bq	becqueret	s^{-1}
Absorbed dose	Gy	gray	$m^2 \cdot s^{-2}$
Dose equivalent	S_v	sievert	$m^2 \cdot s^{-2}$

03.Use of significant figures:



04 Errors , uncertainties ,Precision and accuracy

Introduction

All measurements of physical quantities are subject to uncertainties in the measurements. Variability in the results of repeated measurements arises because variables that can affect the measurement result are impossible to hold constant. Even if the "circumstances," could be precisely controlled, the result would still have an error associated with it. This is because the scale was manufactured with a certain level of quality, it is often difficult to read the scale perfectly, fractional estimations between scale marking may be made and etc. Of course, steps can be taken to limit the amount of uncertainty but it is always there.

In order to interpret data correctly and draw valid conclusions the uncertainty must be indicated and dealt with properly. For the result of a measurement to have clear meaning, the value cannot consist of the measured value alone. An indication of how precise and accurate the result is must also be included. Thus, the result of any physical measurement has two essential components: (1) A numerical value (in a specified system of units) giving the best estimate possible of the quantity measured, and (2) the degree of uncertainty associated with this estimated value. Uncertainty is a parameter characterizing the range of values within which the value of the measurand can be said to lie within a specified level of confidence. For example, a measurement of the width of a table might yield a result such as 95.3 +/- 0.1 cm. This result is basically communicating that the person making the measurement believe the value to be closest to 95.3cm but it could have been 95.2 or 95.4cm. The uncertainty is a quantitative indication of the quality of the result. It gives an answer to the question, "how well does the result represent the value of the quantity being measured?"

The full formal process of determining the uncertainty of a measurement is an extensive process involving identifying all of the major process and environmental variables and evaluating their effect on the measurement. This process is beyond the scope of this material but is detailed in the ISO Guide to the Expression of Uncertainty in Measurement (GUM) and the corresponding American National Standard ANSI/NCSL Z540-2. However, there are measures for estimating uncertainty, such as standard deviation, that are based entirely on the analysis of experimental data when all of the major sources of variability were sampled in the collection of the data set.

The first step in communicating the results of a measurement or group of measurements is to understand the terminology related to measurement quality. It can be confusing, which is partly due to some of the terminology having subtle differences and partly due to the terminology being used wrongly and inconsistently. For example, the term "accuracy" is often used when "trueness" should be used. Using the proper terminology is key to ensuring that results are properly communicated.

True Value

Since the true value cannot be absolutely determined, in practice an accepted reference value is used. The accepted reference value is usually established by repeatedly measuring some NIST or ISO traceable reference standard. This value is not the reference value that is found published in a reference book. Such reference values are not "right" answers; they are measurements that have errors associated with them as well and may not be totally representative of the specific sample being measured

Accuracy and Error

Accuracy is the closeness of agreement between a measured value and the true value. Error is the difference between a measurement and the true value of the measurand (the quantity being measured). Error does not include mistakes. Values that result from reading the wrong value or making some other mistake should be explained and excluded from the data set. Error is what causes values to differ when a measurement is repeated and none of the results can be preferred over the others. Although it is not possible to completely eliminate error in a measurement, it can be controlled and characterized. Often, more effort goes into determining the error or uncertainty in a measurement than into performing the measurement itself.

The total error is usually a combination of systematic error and random error. Many times results are quoted with two errors. The first error quoted is usually the random error, and the second is the systematic error. If only one error is quoted it is the combined error.

Systemic errors

Systematic error tends to shift all measurements in a systematic way so that in the course of a number of measurements the mean value is constantly displaced or varies in a predictable way. The causes may be known or unknown but should always be corrected for when present. For instance, no instrument can ever be calibrated perfectly so when a group of measurements systematically differ from the value of a standard reference specimen, an adjustment in the values should be made. Systematic error can be corrected for only when the "true value" (such as the value assigned to a calibration or reference specimen) is known.

Random errors

Random error is a component of the total error which, in the course of a number of measurements, varies in an unpredictable way. It is not possible to correct for random error. Random errors can occur for a variety of reasons such as:

Lack of equipment sensitivity. An instrument may not be able to respond to or indicate a change in some quantity that is too small or the observer may not be able to discern the change.
Noise in the measurement. Noise is extraneous disturbances that are unpredictable or random and cannot be completely accounted for.
Imprecise definition. It is difficult to exactly define the dimensions of a object. For example, it is difficult to determine the ends of a crack with measuring its length. Two people may likely pick two different starting and ending points.

Trueness and Bias

Trueness is the closeness of agreement between the average value obtained from a large series of test results and an accepted true. The terminology is very similar to that used in accuracy but trueness applies to the average value of a large number of measurements. Bias is the difference between the average value of the large series of measurements and the accepted true. Bias is equivalent to the total systematic error in the measurement and a correction to negate the systematic error can be made by adjusting for the bias.

Precision, Repeatability and Reproducibility

Precision is the closeness of agreement between independent measurements of a quantity under the same conditions. It is a measure of how well a measurement can be made without reference to a theoretical or true value. The number of divisions on the scale of the measuring device generally affects the consistency of repeated measurements and, therefore, the precision. Since precision is not based on a true value there is no bias or systematic error in the value, but instead it depends only on the distribution of random errors. The precision of a measurement is usually indicated by the uncertainty or fractional relative uncertainty of a value.

Repeatability

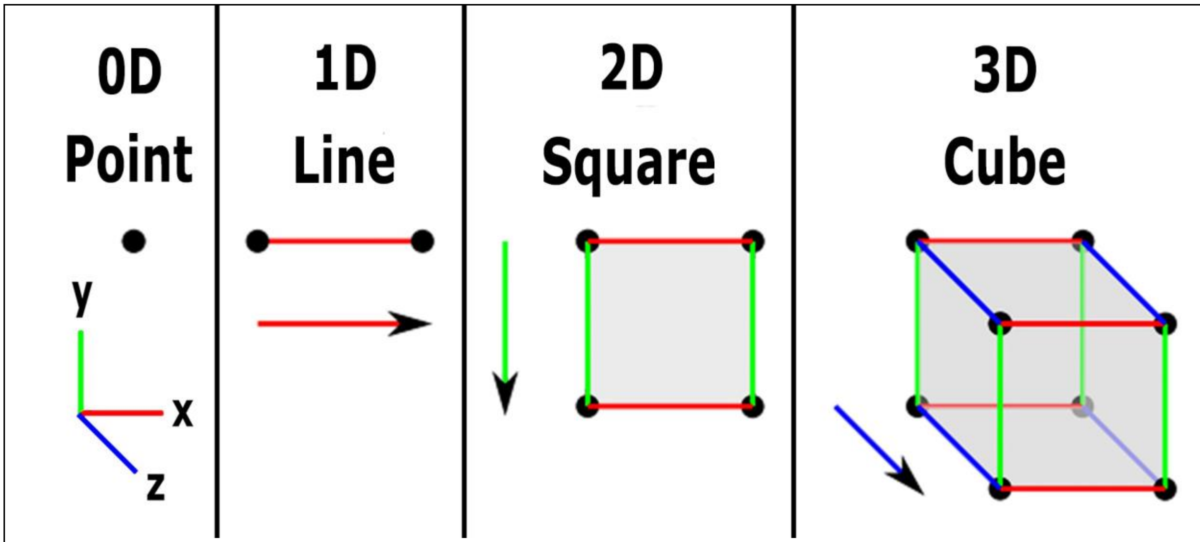
Repeatability is simply the precision determined under conditions where the same methods and equipment are used by the same operator to make measurements on identical specimens. Reproducibility is simply the precision determined under conditions where the same methods but different equipment are used by different operator to make measurements on identical specimens.

Uncertainty

Uncertainty is the component of a reported value that characterizes the range of values within which the true value is asserted to lie. An uncertainty estimate should address error from all possible effects (both systematic and random) and, therefore, usually is the most appropriate means of expressing the accuracy of results. This is consistent with ISO guidelines. However, in many measurement situations the systematic error is not address and only random error is included in the uncertainty measurement. When only random error is included in the uncertainty estimate, it is a reflection of the precision of the measurement.

4.Dimensionality

Dimensionality in statistics refers to how many attributes a dataset has. For example, healthcare data is notorious for having vast amounts of variables (e.g. blood pressure, weight, cholesterol level). In an ideal world, this data could be represented in a spreadsheet, with one column representing each dimension.



Reference pages

https://flexbooks.ck12.org/cbook/ck-12-middle-school-physical-science-flexbook-2.0/section/1.9/primary/lesson/scope-of-physics-ms-ps

https://www.google.com/search?q=SI+base,+supplementary+and+derived+units&rlz=1C1CAFB_enPK904PK905&hl=en&sxsrf=ALeKk03Ow1tmwjQqJlgmB_1IevD7QBAcRw:1591678784937&source=lnms&tbm=isch&sa=X&ved=2ahUKEwjIhsrE-fPpAhVjxKYKHashB0wQ_AUoAXoECBAQAw&biw=1366&bih=576#imgrc=WzDv_Ty2NFG9KM

https://www.nde-ed.org/GeneralResources/ErrorAnalysis/UncertaintyTerms.htm#:~:text=Error%20is%20the%20difference%20between%20the%20true%20value,measurand%20and%20the%20measured%20value.&text=Accuracy%20is%20an%20expression%20of,with%20some%20level%20of%20confidence.

https://www.google.com/search?q=Dimension&tbm=isch&ved=2ahUKEwj6gKSpjvTpAhXM44UKHZgnDTkQ2-cCegQIABAA&oq=Dimension&gs_lcp=CgNpbWcQA1Dh1RRYrN8UYInnFGgAcAB4AIABpgqIAaYKkgEDNy0xmAEAoAEBqgELZ3dzLXdpei1pbWc&sclient=img&ei=DC3fXvrKMszHlwSYz7TIAw&bih=625&biw=1366&rlz=1C1CAFB_enPK904PK905#imgrc=fv2-OKbWxNSjxM

Assessment

Measurement

The main focus of this unit is to introduce and explore measurement as non-standard units can be used to measure objects

Mass is a measure of how heavy an object is. Mass can be measured using non-standard units. Students can make comparison statements.

The activities and problems presented will give the teachers opportunities to assess students' knowledge of linear measurement and mass. Students will be engaged in opportunities to communicate their understandings individually and with others, develop and apply strategies to measure objects and make connections to prior knowledge, justify their thinking and represent their understanding in a variety of ways.

Assessment Methods or Strategies

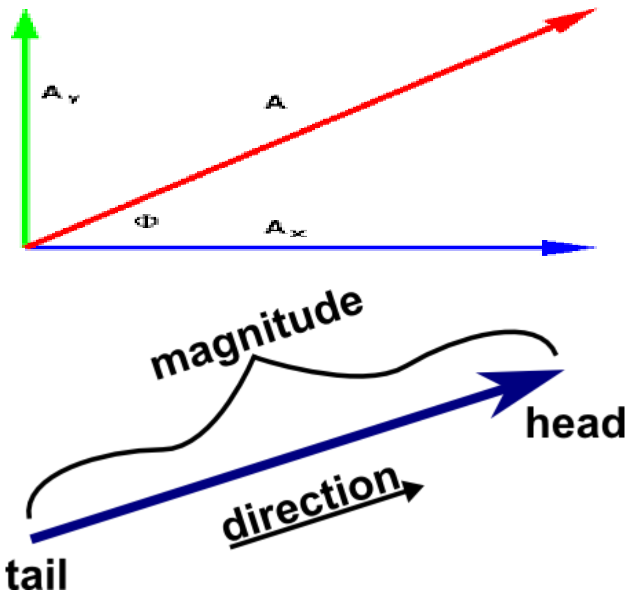
- Whole class/ group observations-checklists
- Individual anecdotal observations- sticky notes
- Individual interviews- with those who need intervention
- Journals or learning logs-written communication and representation- Class Journal on Measurement
- "Show What You Know" or Exemplar Problems to score using a rubric from NCTM

Learning Objectives

- describe the scope of Physics in science, technology and society.
- state SI base units, derived units, and supplementary units for various measurements.
- express derived units as products or quotients of the base units.
- state the conventions for indicating units as set out in the SI units.
- explain why all measurements contain some uncertainty.
- distinguish between systematic errors (including zero errors) and random errors.
- identify that least count or resolution of a measuring instrument is the smallest increment measurable by it.
- differentiate between precision and accuracy.
- assess the uncertainty in a derived quantity by simple addition of actual, fractional or percentage uncertainties.
- quote answers with correct scientific notation, number of significant figures and units in all numerical and practical work.

Unit-02

Vectors and Equilibrium



Topics	Understandings	Skills
• Cartesian coordinate system • Addition of vectors by head to • tail rule • Addition of vectors by • perpendicular components • Scalar product of two vectors • Vectors product of two vectors • Torque • Equilibrium of forces • Equilibrium of torques	• Students will be able to: • Describe the Cartesian coordinate system. • Determine the sum of vectors using head to tail rule. • Represent a vector into two perpendicular components. • Determine the sum of vectors using perpendicular components. • Describe scalar product of two vectors in term of angle between them. • Describe vector product of two vectors in term of angle between them. • State the method to determine the direction of vector product of two vectors. • Define the torque as vector product r x F. • List applications of torque or moment due to a force. • State first condition of equilibrium. • Sate second condition of equilibrium. • Solve two dimensional problems involving forces (statics) using 1st and 2nd Conditions of equilibrium.	• Students will be able to: • Determine the weight of a body by vector addition of forces using perpendicular components. • Verify the two conditions of • equilibrium using a suspended metre rod.

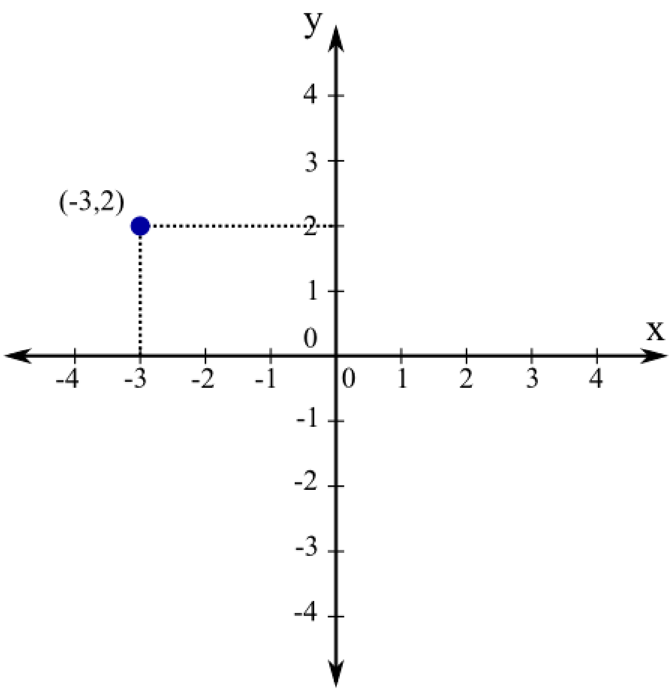
Unit overview

Cartesian coordinates

Cartesian coordinates allow one to specify the location of a point in the plane, or in three-dimensional space. The Cartesian coordinates (also called rectangular coordinates) of a point are a pair of numbers (in two-dimensions) or a triplet of numbers (in three-dimensions) that specified signed distances from the coordinate axis.

Cartesian coordinates of the plane

The Cartesian coordinates in the plane are specified in terms of the *x*-coordinates axis and the *y*-coordinate axis, as illustrated in the below figure. The origin is the intersection of the *x* and *y*-axes. The Cartesian coordinates of a point in the plane are written as (x,y). The first number *x* is called the *x*-coordinate (or *x*-component), as it is the signed distance from the origin in the direction along the *x*-axis. The *x*-coordinate specifies the distance to the right (if *x* is positive) or to the left (if *x* is negative) of the *y*-axis. Similarly, the second number *y* is called the *y*-coordinate (or *y*-component), as it is the signed distance from the origin in the direction along the *y*-axis, The *y*-coordinate specifies the distance above (if *y* is positive) or below (if *y* is negative) the *x*-axis. The following figure, the point has coordinates $(-3,2)$, as the point is three units to the left and two units up from the origin.



Addition of vectors by Head to Tail method

To add vector v to vector u Move vector v (keeping its length and orientation the same) until its tail touches the head of u. The sum is the vector from the tail of u to the head of v

Addition of vectors by Head to Tail method (Graphical Method)

Head to Tail method or graphical method is one of the easiest method used to find the resultant vector of two of more than two vectors.

DETAILS OF METHOD

Consider two vectors $\vec{A}$ and $\vec{B}$ acting in the directions as shown below:

In order to get their resultant vector by head to tail method we must follow the following steps:

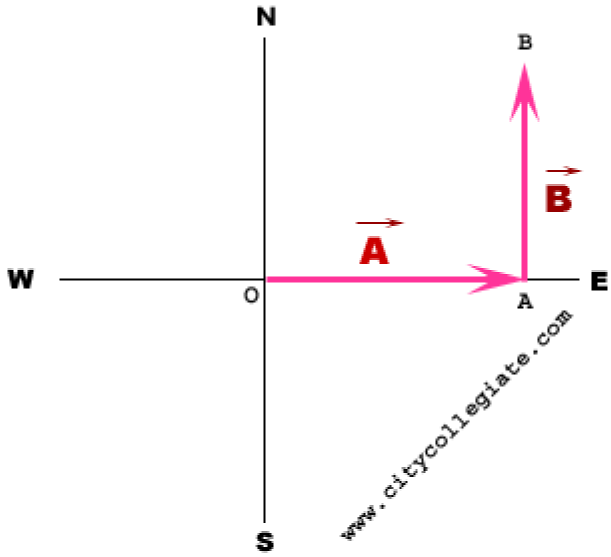
STEP # 1

Choose a suitable scale for the vectors so that they can be plotted on the paper.

STEP # 2

Draw representative line $\overline{OA}$ of vector $\vec{A}$

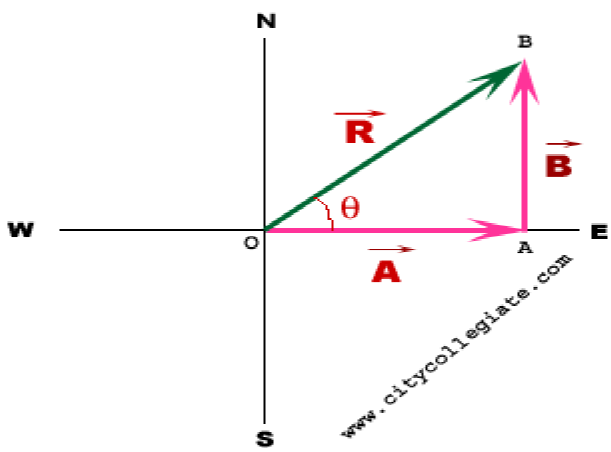
Draw representative line $\overline{AB}$ of vector $\vec{B}$ such that the tail of $\vec{B}$ coincides with the head of vector $\vec{A}$.



STEP # 3

Join 'O' and 'B'.

$\overline{OB}$ represents resultant vector of given vectors $\vec{A}$ and $\vec{B}$ i.e.



$$\overline{OB} = \overline{OA} + \overline{AB}$$

$$\vec{R} = \vec{A} + \vec{B}$$

STEP # 4

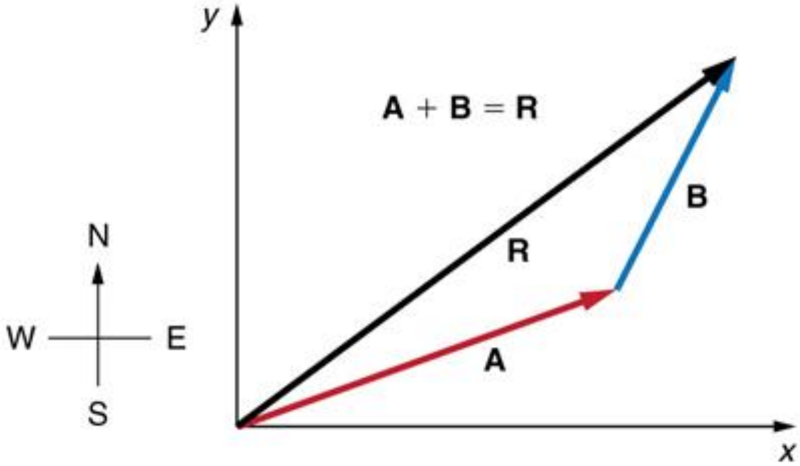
Measure the length of line segment $\overline{OB}$ and multiply it with the scale choosen initially to get the magnitude of resultant vector.

STEP # 5

The direction of the resultant vector is directed from the tail of vector $\vec{A}$ to the head of vector $\vec{B}$

Addition of vectors by perpendicular components.

To see how to add vectors using perpendicular components, consider Figure, in which the vectors *A* and *B* are added to produce the resultant *R*

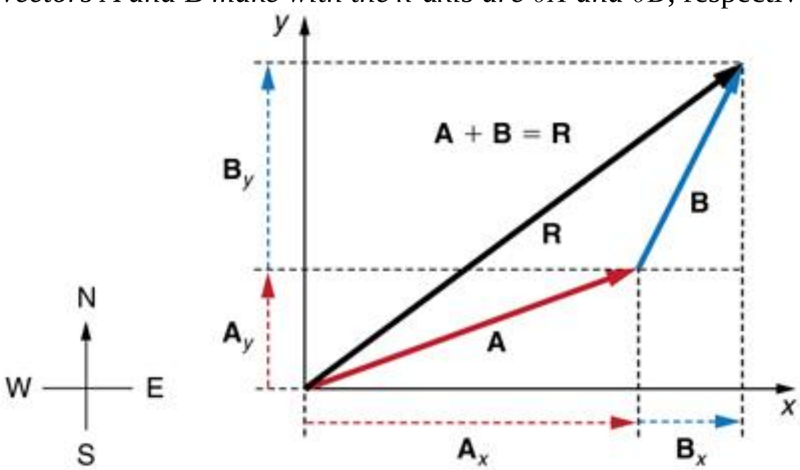


Vectors *A* and *B* are two legs of a walk, and *R* is the resultant or total displacement. You can use analytical methods to determine the magnitude and direction of *R*

If *A* and *B* represent two legs of a walk (two displacements), then *R* is the total displacement. The person taking the walk ends up at the tip of R. There are many ways to arrive at the same point. In particular, the person could have walked first in the x-direction and then in the y-direction. Those paths are the x- and y-components of the resultant, *Rx* and *Ry*. If we know *Rx* and *Ry*, we can find *R* and *θ* using the equations A=√(A2x+A2y) and θ=tan–1(Ay/Ax)

When you use the analytical method of vector addition, you can determine the components or the magnitude and direction of a vector.

Step 1. Identify the x- and y-axes that will be used in the problem. Then, find the components of each vector to be added along the chosen perpendicular axes. *Use the equations Ax=Acosθ and Ay=Asinθ to find the components. In Figure, these components are Ax,Ay,Bx, and By. The angles that vectors A and B make with the x-axis are θA and θB*, respectively.



To add vectors *A* and *B*, first determine the horizontal and vertical components of each vector. These are the dotted vectors *Ax*,*Ay*,*Bx* and *B*−*y*

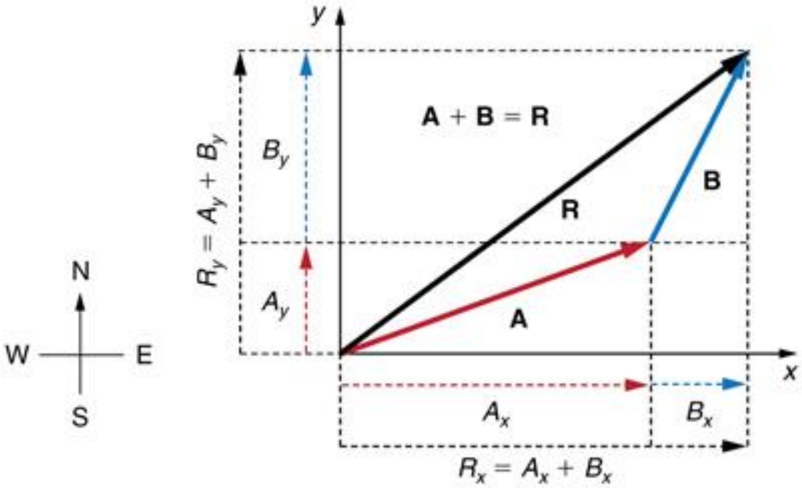
shown in the image.

Step 2. Find the components of the resultant along each axis by adding the components of the individual vectors along that axis. That is, as shown in Figure,

Rx=*Ax*+*Bx*

and

$R_y = A_y + B_y$.



The magnitude of the vectors A_x and B_x add to give the magnitude R_x of the resultant vector in the horizontal direction. Similarly, the magnitudes of the vectors A_y and B_y add to give the magnitude R_y of the resultant vector in the vertical direction.

Components along the same axis, say the *x*-axis, are vectors along the same line and, thus, can be added to one another like ordinary numbers. The same is true for components along the *y*-axis. (For example, a 9-block eastward walk could be taken in two legs, the first 3 blocks east and the second 6 blocks east, for a total of 9, because they are along the same direction.) So resolving vectors into components along common axes makes it easier to add them. Now that the components of *R* are known, its magnitude and direction can be found.

Step 3. To get the magnitude R of the resultant, use the Pythagorean theorem:

R=R2x+R2y−−−−−−−n

Step 4. To get the direction of the resultant:

$\theta = tan^{-1}(R_y/R_x)$

Scalar product of two vectors

One of the ways in which two vectors can be combined is known as the scalar product. When we calculate the scalar product of two vectors the result, as the name suggests is a scalar, rather than a vector .In this unit you will learn how to calculate the scalar product and meet some geometrical applications

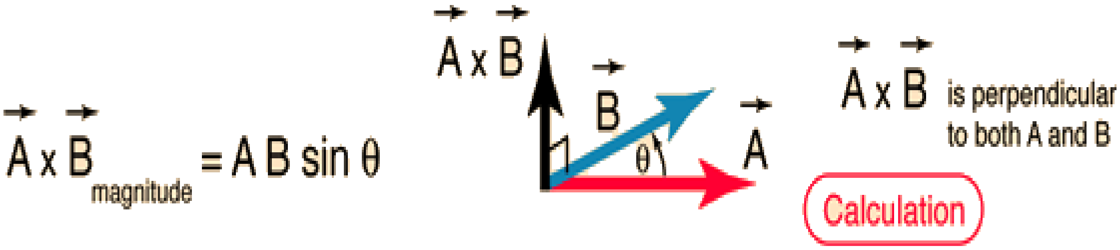
. Definition of the scalar product Study the two vectors a and b drawn in Figure 1. Note that we have drawn the two vectors so that their tails are at the same point. The angle between the two vectors has been labeled θ. Two vectors ,a and b, drawn so that the angle between them is θ. We define the scalar product of a and b as follows

The scalar product of a and b is defined to be $a \cdot b = |a||b|\cos\theta$ where |a| is the modulus, or magnitude of a, |b| is the modulus of b, and θ is the angle between a and b

Vectors product of two vectors

The cross product a × b is defined as a vector c that is perpendicular (orthogonal) to both a and b, with a direction given by the right-hand rule and a magnitude equal to the area of the parallelogram that the vectors span

The vector product and the scalar product are the two ways of multiplying vectors which see the most application in physics and astronomy. The magnitude of the vector product of two vectors can be constructed by taking the product of the magnitudes of the vectors times the sine of the angle (<180 degrees) between them. The magnitude of the vector product can be expressed in the form:



and the direction is given by the right-hand rule. If the vectors are expressed in terms of unit vectors i, j, and k in the x, y, and z directions, then the vector product can be expressed in the rather cumbersome form:

$$\vec{A} \times \vec{B} = \vec{i}(A_y B_z - A_z B_y) - \vec{j}(A_x B_z - A_z B_x) + \vec{k}(A_x B_y - A_y B_x)$$

which may be stated somewhat more compactly in the form of a determinant.

Torque

Torque, moment, moment of force, rotational force or "turning effect" is the rotational equivalent of linear force. The concept originated with the studies by Archimedes of the usage of levers. Just as a linear force is a push or a pull, a torque can be thought of as a twist to an object around a specific axis. Another definition of torque is the product of the magnitude of the force and the perpendicular distance of the line of action of force from the axis of rotation. The symbol for torque is typically t, the lowercase Greek letter *tau*. When being referred to as moment of force, it is commonly denoted by *M*.

In three dimensions, the torque is a pseudovector; for point particles, it is given by the cross product of the position vector (distance vector) and the force vector. The magnitude of torque of a rigid body depends on three quantities: the force applied, the *lever arm vector*[connecting the point about which the torque is being measured to the point of force application, and the angle between the force and lever arm vectors. In symbols:

t=Fxr

t=|F|x|r| sinΘ

where,

t is the torque vector and t is the magnitude of the torque,

r is the position vector (a vector from the point about which the torque is being measured to the point where the force is applied)

F is the force vector,

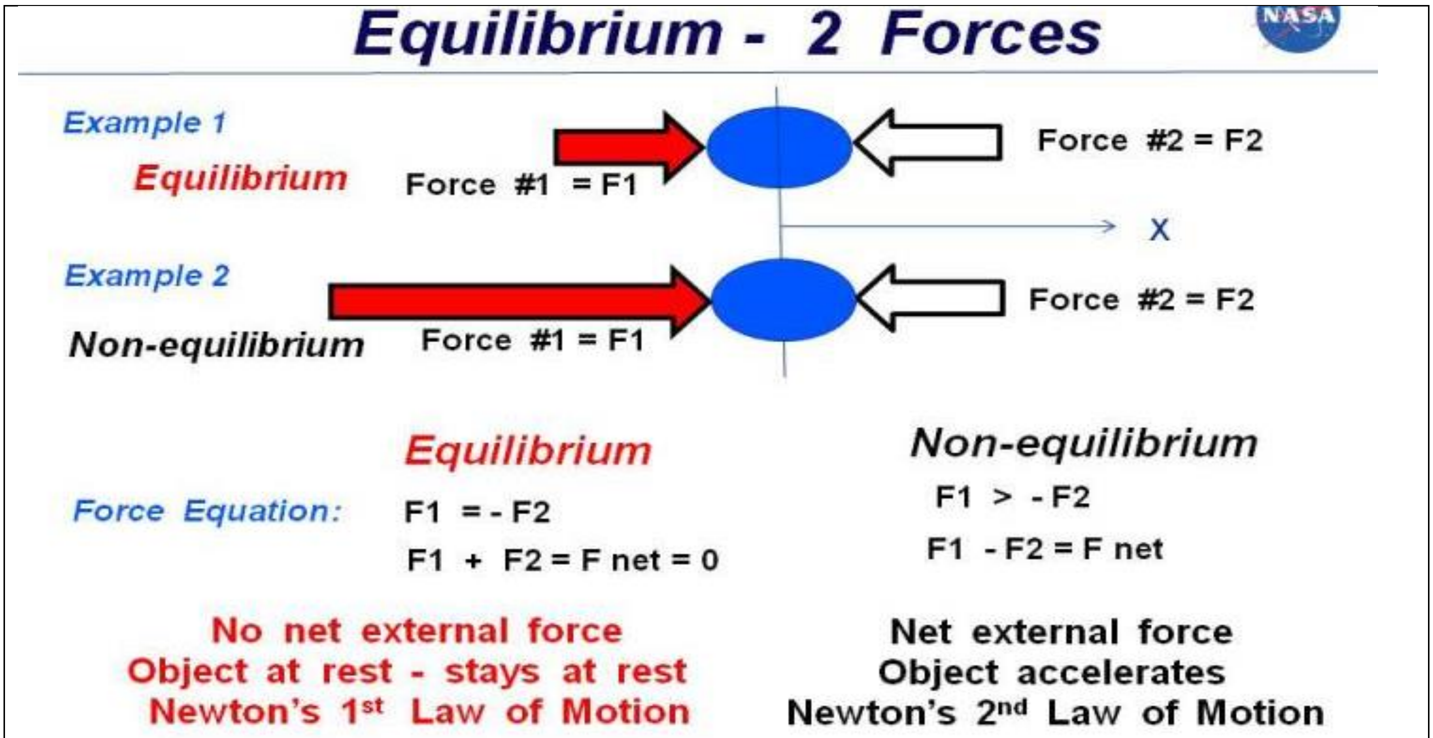
× denotes the cross product, which produces a vector that is perpendicular to both r and F following the right-hand rule,

Θ is the angle between the force vector and the lever arm vector.

The SI unit for torque is N·m.

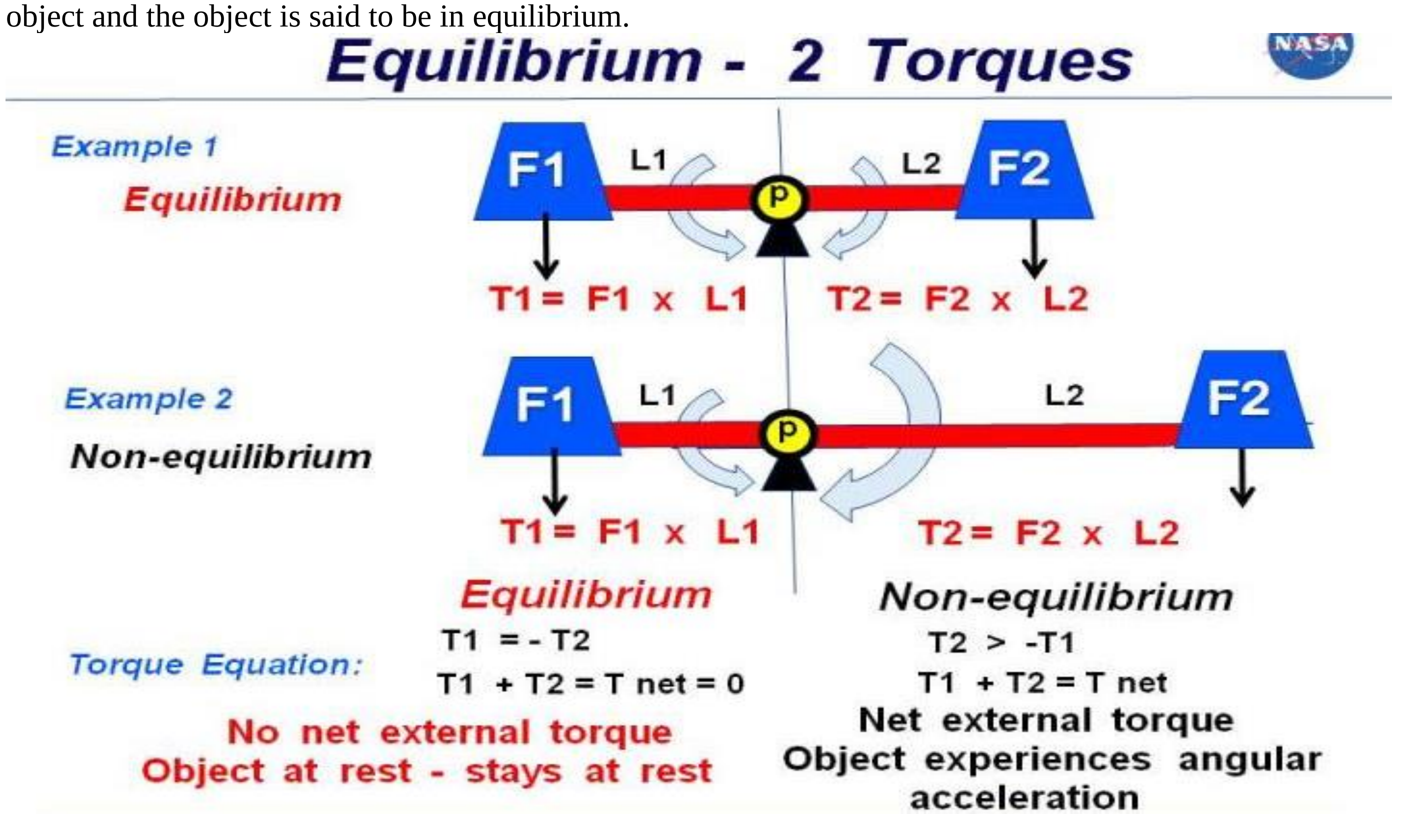
Equilibrium of forces

A force is a vector quantity which means that it has both a magnitude (size) and a direction associated with it. If the size and direction of the forces acting on an object are exactly balanced, then there is no net force acting on the object and the object is said to be in equilibrium.

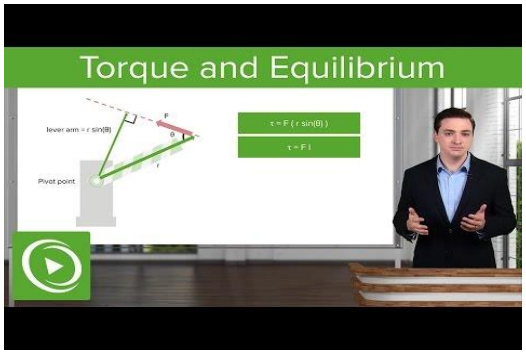


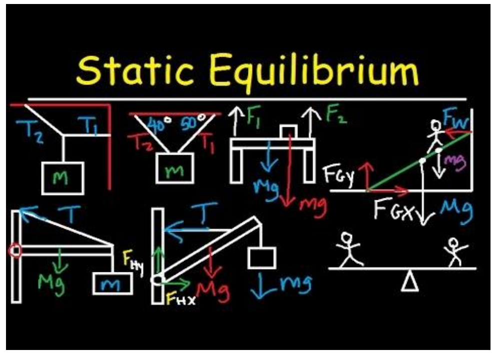
Equilibrium of torques

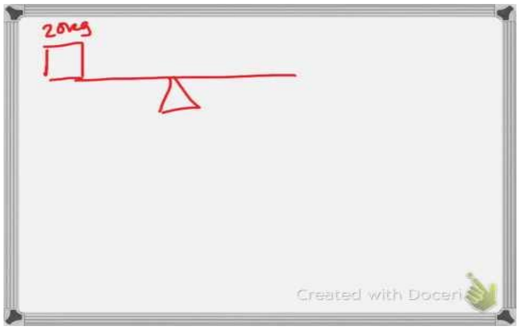
A very basic concept when dealing with torques is the idea of equilibrium or balance. ... If the size and direction of the torques acting on an object are exactly balanced, then there is no net torque acting on the object and the object is said to be in equilibrium.

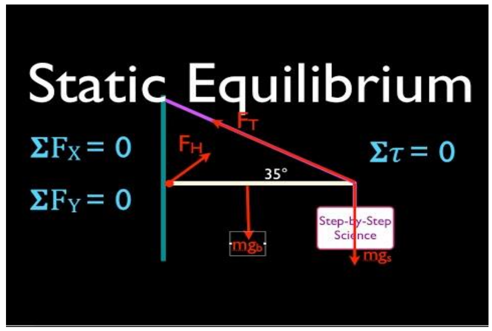


Videos









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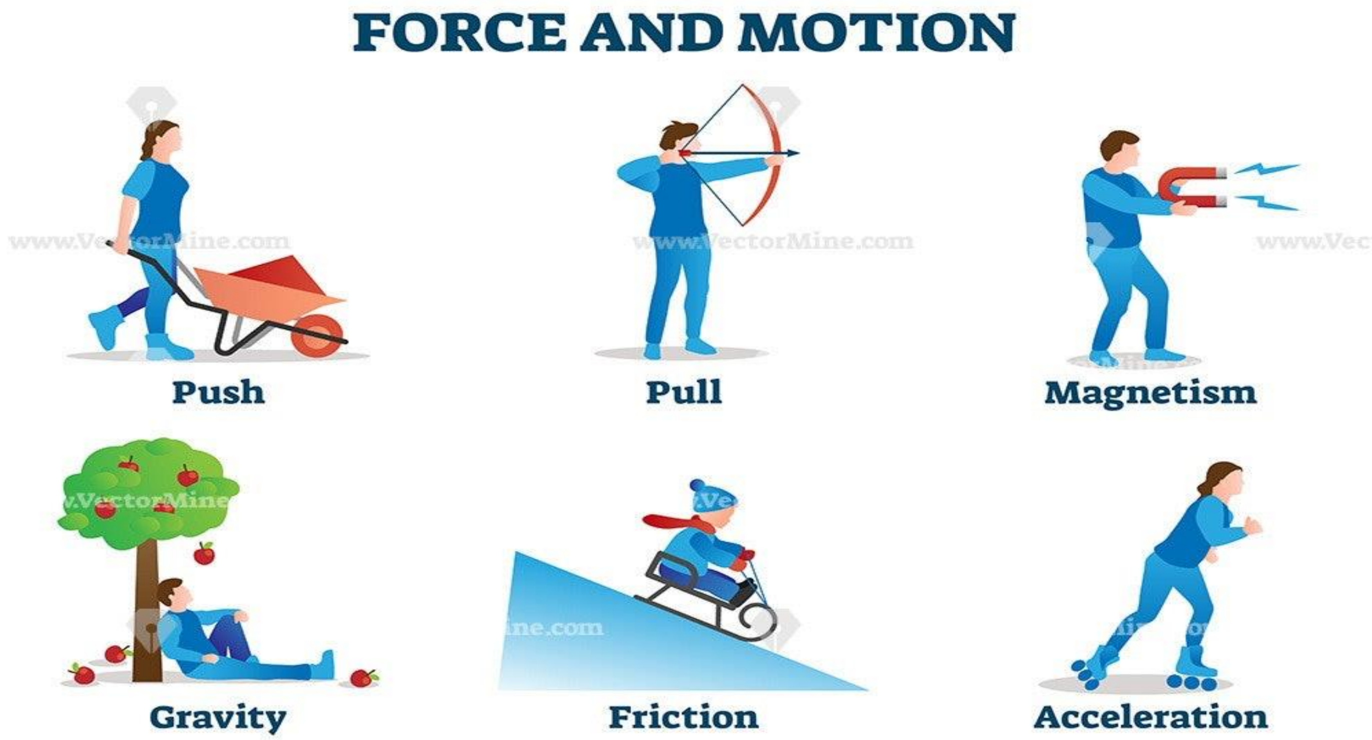
Learning Outcomes

The students will:

- Describe the Cartesian coordinate system.
- Determine the sum of vectors using head to tail rule.
- Represent a vector into two perpendicular components.
- Determine the sum of vectors using perpendicular components.
- Describe scalar product of two vectors in term of angle between them.
- Describe vector product of two vectors in term of angle between them.
- State the method to determine the direction of vector product of two vectors.
- Define the torque as vector product r x F.
- List applications of torque or moment due to a force.
- State first condition of equilibrium.
- State second condition of equilibrium.

Solve two dimensional problems involving forces (statics) using 1st and 2^{nd} conditions of equilibrium.

Unit-3



Topics	Understandings	Skills
• Displacement • Average velocity and • instantaneous velocity • Average acceleration and • instantaneous acceleration • Review of equations of • uniformly accelerated motion • Newton's laws of motion • Momentum and Impulse • Law of conservation of • momentum • Elastic collisions in one • Dimension • Momentum and explosive forces • Projectile motion • Rocket motion	• The students will: • Describe vector nature of • displacement. • Describe average and instantaneous velocities of objects. • Compare average and instantaneous speeds with average and instantaneous Velocities. • Interpret displacement-time and velocity-time graphs of objects moving along the same straight line. • Determine the instantaneous velocity of an object moving along the same straight line by measuring the slope of displacement-time graph. • Define average acceleration (rate of change of velocity aav = Δv / Δt)	The students will: • Analyze and interpret patterns of motion of objects using (i) Displacement-time graph (ii) Velocity-time graph (iii) Acceleration-time graph • Measure the free fall time of a ball using a ticker-timer and hence calculate the value of "g". • Evaluate your result and identify the sources of error and suggest improvements. • Investigate the value of "g" by free fall method • Investigate momentum conservation by colliding trolleys and ticker-timer for elastic and inelastic collisions • Investigate the downward force, along an inclined plane, acting on a roller due to gravity and study its relationship with the angle of inclination by plotting graph between force and sin θ

	and instantaneous acceleration (as the limiting value of average acceleration • Distinguish between positive and negative acceleration, uniform and variable acceleration. • Determine the instantaneous acceleration of an object measuring the slope of velocity-time graph. • Manipulate equation of uniformly accelerated motion to solve problems. • Explain that projectile motion is two dimensional motion in a vertical plane. • Communicate the ideas of a projectile in the absence of air resistance that. Horizontal component (VH) of velocity is constant. • Acceleration is in the vertical direction and is the same as that of a vertically free falling object. • The horizontal motion and vertical motion are independent of each other. • Evaluate using equations of uniformly accelerated motion that for a given initial velocity of frictionless projectile. 1. How higher does it go? 2. How far would it go along the level land? 3. Where would it be after a given time? 4. How long will it remain in air? • Determine for a projectile launched from ground height. 1. launch angle that results in the maximum range. 2. Relation between the launch angles that result in the same range. • Describe how air resistance affects	

	both the horizontal component and vertical component of velocity and hence the range of the projectile. • Apply Newton's laws to explain the motion of objects in a variety of context. • Define mass (as the property of a body which resists change in motion). • Describe and use of the concept of weight as the effect of a gravitational field on a mass. • Describe the Newton's second law of motion as rate of change of momentum. • Co-relate Newton's third law of motion and conservation of momentum. • Show awareness that Newton's Laws are not exact but provide a good approximation, unless an object is moving close to the speed of light or is small enough that quantum effects become significant. • Define Impulse (as a product of impulsive force and time). • Describe the effect of an impulsive force on the momentum of an object, and the effect of lengthening the time, stopping, or rebounding from the collision. • Describe that while momentum of a system is always conserved in interaction between bodies some change in K.E. usually takes place. • Solve different problems of elastic and inelastic collisions between two bodies in one dimension by using law of conservation of momentum. • Describe that momentum is conserved in all situations.	

	• Identify that for a perfectly elastic collision, the relative speed of approach is equal to the relative speed of separation. • Differentiate between explosion and collision (objects move apart instead of coming nearer).	

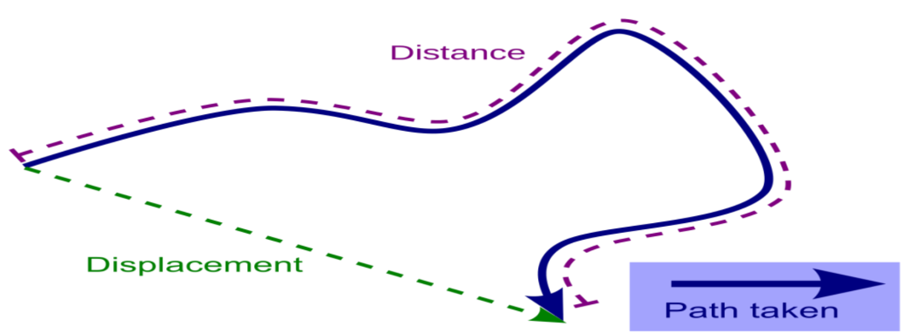
Science, Technology and Society Connections

The students will:

• Outline the forces involved in causing a change in the velocity of a vehicle when
• Coasting with no pressure on the acceleration.
• Pressing on the accelerator.
• Pressing on the brakes.
• Passing over an icy patch on the road.
• Climbing and descending hills.
• Investigate and explain the effect of the launch height of a projectiles (e.g. a shot put launched from a shoulder height) on a maximum range and the affect of launch angle for a given height.
• Describe to what extent the air resistance affects various projectiles in sports
• Evaluate the effectiveness of some safety features of motor vehicles in connection with the changing momentum such as safety helmet, seat belt, head rest of the car seat.
• Describe the conservation of momentum for (i) car crashes (ii) ball & bat.
• Assess the reasons for the introduction of low speed zones in built-up areas and the addition of air bags and crumple zones to vehicles with respect to the concepts of impulse and momentum.
• Explain in terms of law of conservation of momentum, the motion under thrust of a rocket in a straight line considering short thrusts during which the mass remains constant
• Describe the nature of the rocket thrusts necessary to cause a space vehicle to change direction along a circular arc in a region of space where gravity is negligible.

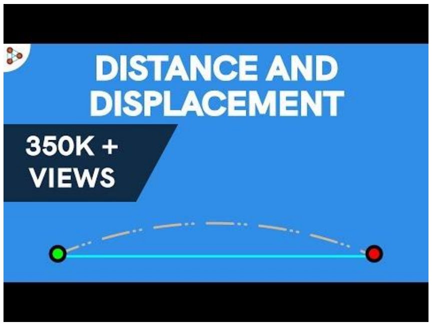
Unit overview

Displacement



A *displacement* is a vector whose length is the shortest distance from the initial to the final position of a point P undergoing motion. It quantifies both the distance and direction of the net or total motion along a straight line from the initial position to the final position of the point trajectory.

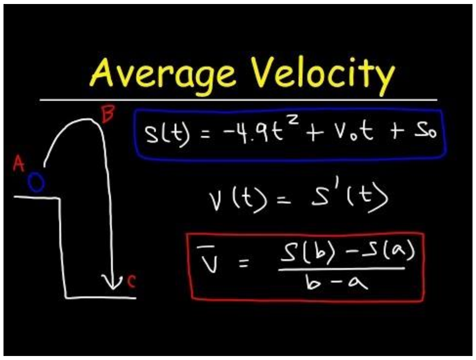
Videos:



Average velocity and instantaneous velocity

The **instantaneous velocity** is the specific rate of change of position (or displacement) with respect to time at a single point (x,t) , while **average velocity** is the **average** rate of change of position (or displacement) with respect to time over an interval.

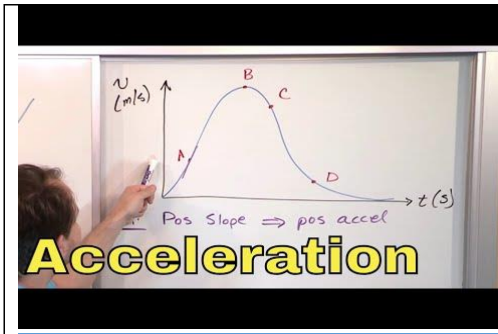
Video:



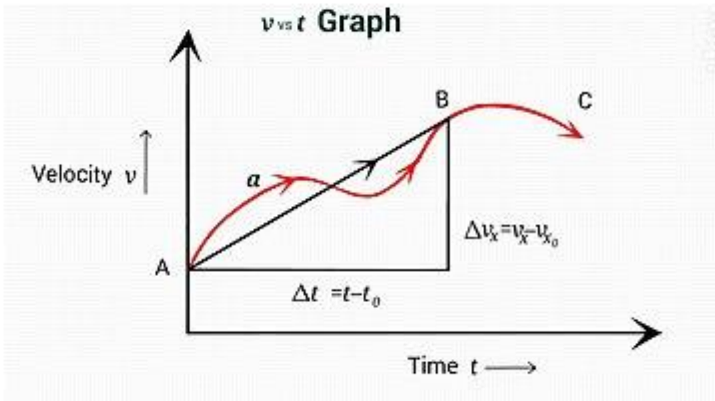
Average acceleration and instantaneous acceleration

Average acceleration is the change of velocity over a period of time. **Instantaneous acceleration** is the change of velocity over an instance of time. Constant or uniform **acceleration** is when the velocity changes the same amount in every equal time period

Video:



Review of equations of uniformly accelerated motion



First Equation **of motion**. The first equation **of motion** is v = u +at v = u + a t , where v is the final velocity and u is ...

Second Equation **of motion**. Second equation **of motion** gives distance traveled by a moving body in time t. ...

Third equation **of motion**. This equation gives the velocity acquired by the body in traveling a distance s

Uniform acceleration

The differential equation of motion for a particle of constant or uniform acceleration in a straight line is simple: the acceleration is constant, so the second derivative of the position of the object is constant. The results of this case are summarized below.

Constant translational acceleration in a straight line

These equations apply to a particle moving linearly, in three dimensions in a straight line with constant acceleration Since the position, velocity, and acceleration are collinear (parallel, and lie on the same line) – only the magnitudes of these vectors are necessary, and because the motion is along a straight line, the problem effectively reduces from three dimensions to one.

$$v = u + at$$

$$s = \left(\frac{u+v}{2}\right) t$$

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

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

$$s = vt - \frac{1}{2}at^2$$

Newton's laws of motion

Newton's first law

Main article: Inertia

The first law states that if the net force (the vector sum of all forces acting on an object) is zero, then the velocity of the object is constant. Velocity is a vector quantity which expresses both the object's speed and the direction of its motion; therefore, the statement that the object's velocity is constant is a statement that both its speed and the direction of its motion are constant.

The first law can be stated mathematically when the mass is a non-zero constant, as,
Consequently,

- An object that is at rest will stay at rest unless a force acts upon it.
- An object that is in motion will not change its velocity unless a force acts upon it.

This is known as *uniform motion*. An object *continues* to do whatever it happens to be doing unless a force is exerted upon it. If it is at rest, it continues in a state of rest (demonstrated when a tablecloth is skilfully whipped from under dishes on a tabletop and the dishes remain in their initial state of rest). If an object is moving, it continues to move without turning or changing its speed. This is evident in space probes that continuously move in outer space. Changes in motion must be imposed against the tendency of an object to retain its state of motion. In the absence of net forces, a moving object tends to move along a straight line path indefinitely.

Newton placed the first law of motion to establish frames of reference for which the other laws are applicable. However, Newton implicitly referred to the absolute co-ordinate of cosmos for this frame. Since we cannot precisely measure our velocity relative to a far star, Newton's frame is based on a pure imagination, not based on measurable physics. In current physics, an observer defines himself as in inertial frame by preparing one stone hooked by a spring, and rotating the spring to any direction, and observing the stone static and the length of that spring unchanged. By Einstein's equivalence principle, if there was one such observer A and another observer B moving in a constant velocity related to A, then A and B will both observe the same physics phenomena. if A verified the first law, then B will verify it too. In this way, the definition of inertial can get rid of absolute space or far star, and only refer to the objects locally reachable and measurable.

A particle not subject to forces moves (related to inertial frame) in a straight line at a constant speed.[11][17] Newton's first law is often referred to as the *law of inertia*. Thus, a condition necessary for the uniform motion of a particle relative to an inertial reference frame is that the total net force acting on it is zero. In this sense, the first law can be restated as:

In every material universe, the motion of a particle in a preferential reference frame Φ is determined by the action of forces whose total vanished for all times when and only when the velocity of the particle is constant in Φ. That is, a particle initially at rest or in uniform motion in the preferential frame Φ continues in that state unless compelled by forces to change it.[18]

Newton's first and second laws are valid only in an inertial reference frame. Any reference frame that is in uniform motion with respect to an inertial frame is also an inertial frame, i.e. Galilean invariance or the principle of Newtonian relativity.

Newton's second law

The second law states that the rate of change of momentum of a body is directly proportional to the force applied, and this change in momentum takes place in the direction of the applied force.
The second law can also be stated in terms of an object's acceleration. Since Newton's second law is valid only for constant-mass systems, *m* can be taken outside the differentiation operator by the constant factor rule in

differentiation. Thus
where **F** is the net force applied, *m* is the mass of the body, and **a** is the body's acceleration. Thus, the net force applied to a body produces a proportional acceleration. In other words, if a body is accelerating, then there is a force on it. An application of this notation is the derivation of G Subscript C.
The above statements hint that the second law is merely a definition of , not a precious observation of nature. However, current physics restate the second law in measurable steps:
(1) defining the term 'one unit of mass' by a specified stone,
(2) defining the term 'one unit of force' by a specified spring with specified length,
(3) measuring by experiment or proving by theory (with a principle that every direction of space are equivalent), that force can be added as a mathematical vector,
(4) finally conclude that . These steps hint the second law is a precious feature of nature.
The second law also implies the conservation of momentum: when the net force on the body is zero, the momentum of the body is constant. Any net force is equal to the rate of change of the momentum.
Any mass that is gained or lost by the system will cause a change in momentum that is not the result of an external force. A different equation is necessary for variable-mass systems (see below).
Newton's second law is an approximation that is increasingly worse at high speeds because of relativistic effects.
According to modern ideas of how Newton was using his terminology,[23] the law is understood, in modern terms, as an equivalent of:
The change of momentum of a body is proportional to the impulse impressed on the body, and happens along the straight line on which that impulse is impressed.

This may be expressed by the formula , where is the time derivative of the momentum . This equation can be seen clearly in the Wren Library of Trinity College, Cambridge, in a glass case in which Newton's manuscript is open to the relevant page.
Motte's 1729 translation of Newton's Latin continued with Newton's commentary on the second law of motion, reading:
If a force generates a motion, a double force will generate double the motion, a triple force triple the motion, whether that force be impressed altogether and at once, or gradually and successively. And this motion (being always directed the same way with the generating force), if the body moved before, is added to or subtracted from the former motion, according as they directly conspire with or are directly contrary to each other; or obliquely joined, when they are oblique, so as to produce a new motion compounded from the determination of both.

The sense or senses in which Newton used his terminology, and how he understood the second law and intended it to be understood, have been extensively discussed by historians of science, along with the relations between Newton's formulation and modern formulations.[24]

Impulse

An impulse **J** occurs when a force **F** acts over an interval of time Δ*t*, and it is given by[25][26]

Since force is the time derivative of momentum,

This relation between impulse and momentum is closer to Newton's wording of the second law.[27]

Impulse is a concept frequently used in the analysis of collisions and impacts.[28]

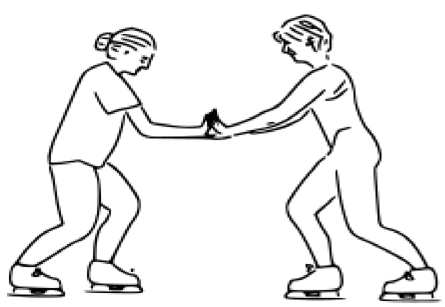
Variable-mass systems

Variable-mass systems, like a rocket burning fuel and ejecting spent gases, are not closed and cannot be directly treated by making mass a function of time in the second law;[21] that is, the following formula is wrong:[22]

The falsehood of this formula can be seen by noting that it does not respect Galilean invariance: a variable-mass object with $\mathbf{F} = 0$ in one frame will be seen to have $\mathbf{F} \neq 0$ in another frame.[20] The correct equation of motion for a body whose mass *m* varies with time by either ejecting or accreting mass is obtained by applying the second law to the entire, constant-mass system consisting of the body and its ejected/accreted mass; the result is

where **u** is the velocity of the escaping or incoming mass relative to the body. From this equation one can derive the equation of motion for a varying mass system, for example, the Tsiolkovsky rocket equation. Under some conventions, the quantity $\mathbf{u}\, dm/dt$ on the left-hand side, which represents the advection of momentum, is defined as a force (the force exerted on the body by the changing mass, such as rocket exhaust) and is included in the quantity **F**. Then, by substituting the definition of acceleration, the equation becomes $\mathbf{F} = m\mathbf{a}$.

Newton's third law



An illustration of Newton's third law in which two skaters push against each other. The first skater on the left exerts a normal force N_{12} on the second skater directed towards the right, and the second skater exerts a normal force N_{21} on the first skater directed towards the left.

The magnitudes of both forces are equal, but they have opposite directions, as dictated by Newton's third law.

The third law states that all forces between two objects exist in equal magnitude and opposite direction: if one object *A* exerts a force $\mathbf{F}_A$ on a second object *B*, then *B* simultaneously exerts a force $\mathbf{F}_B$ on *A*, and the two forces are equal in magnitude and opposite in direction: $\mathbf{F}_A = -\mathbf{F}_B$.[29] The third law means that all forces are *interactions* between different bodies,[30][31] or different regions within one body, and thus that there is no such thing as a force that is not accompanied by an equal and opposite force. In some situations, the magnitude and direction of the forces are determined entirely by one of the two bodies, say Body *A*; the force exerted by Body *A* on Body *B* is called the "action", and the force exerted by Body *B* on Body *A* is called the "reaction". This law is sometimes referred to as the *action-reaction law*, with $\mathbf{F}_A$ called the "action" and $\mathbf{F}_B$ the "reaction". In other situations the magnitude and directions of the forces are determined jointly by both bodies and it isn't necessary to identify one force as the "action" and the other as the "reaction". The action and the reaction are simultaneous, and it does not matter which is called the *action* and which is called *reaction*; both forces are part of a single interaction, and neither force exists without the other.[29]

The two forces in Newton's third law are of the same type (e.g., if the road exerts a forward frictional force on an accelerating car's tires, then it is also a frictional force that Newton's third law predicts for the tires pushing backward on the road).

From a conceptual standpoint, Newton's third law is seen when a person walks: they push against the floor, and the floor pushes against the person. Similarly, the tires of a car push against the road while the road pushes back on the tires—the tires and road simultaneously push against each other. In swimming, a person interacts with the water, pushing the water backward, while the water simultaneously pushes the person forward—both the person and the water push against each other. The reaction forces account for the motion in these examples. These forces depend on friction; a person or car on ice, for example, may be unable to exert the action force to produce the needed reaction force.[32]

Newton used the third law to derive the law of conservation of momentum;[33] from a deeper perspective, however, conservation of momentum is the more fundamental idea (derived via Noether's theorem from Galilean invariance), and holds in cases where Newton's third law appears to fail, for instance when force fields as well as particles carry momentum, and in quantum mechanics.

Video

Momentum and Impulse

Momentum

The momentum of a body is equal to its mass multiplied by its velocity.
Momentum is measured in N s. Note that momentum is a vector quantity, in other words the direction is important.

Impulse

The impulse of a force (also measured in N s) is equal to the change in momentum of a body which a force causes. This is also equal to the magnitude of the force multiplied by the length of time the force is applied.

- Impulse = change in momentum = force × time

Video

Law of conservation of momentum states that

For two or more bodies in an isolated system acting upon each other, their total momentum remains constant unless an external force is applied. Therefore, momentum can neither be created nor destroyed.

Derivation of Conservation of Momentum

Consider two colliding particles A and B whose masses are m1 and m2 with initial and final velocities as u1 and v1 of A and u2 and v2 of B. The time of contact between two particles is given as t.

$A=m_1(v_1-u_1)$ (change in momentum of particle A)

$B=m_2(v_2-u_2)$ (change in momentum of particle B)

$F_{BA}=-F_{AB}$ (from third law of motion)

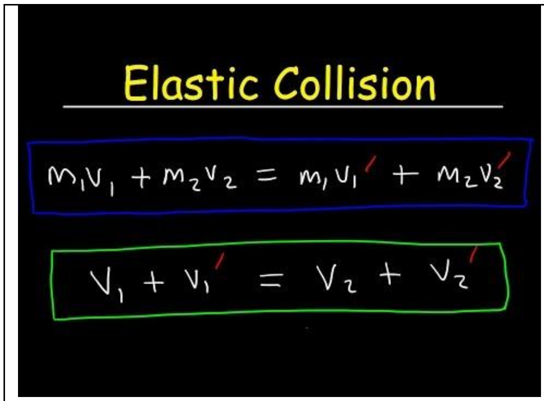
$F_{BA}=m_2*a_2=m_2(v_2-u_2)t$ $F_{AB}=m_1*a_1=m_1(v_1-u_1)t$ $m_2(v_2-u_2)t=-m_1(v_1-u_1)t$ $m_1u_1+m_2u_2=m_1v_1+m_2v_2$

Therefore, above is the equation of law of conservation of momentum where, $m_1u_1+m_2u_2$ is the representation of total momentum of particles A and B before collision and $m_1v_1+m_2v_2$ is the representation of total momentum of particles A and B after collision

Elastic collisions in one dimension

An elastic collision is one that conserves internal kinetic energy. Conservation of kinetic energy and momentum together allow the final velocities to be calculated in terms of initial velocities and masses in one dimensional two-body collisions.

Video



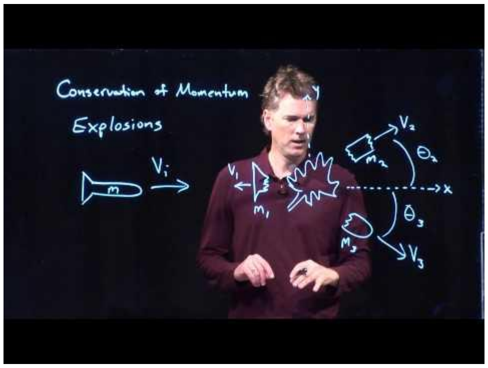
Momentum and explosive forces

Whether it is a collision or an explosion, if it occurs in an isolated system, then each object involved encounters the same impulse to cause the same momentum change. The impulse and momentum change on each object are equal in magnitude and opposite in direction. Thus, the total system momentum is conserved

What are explosive forces?

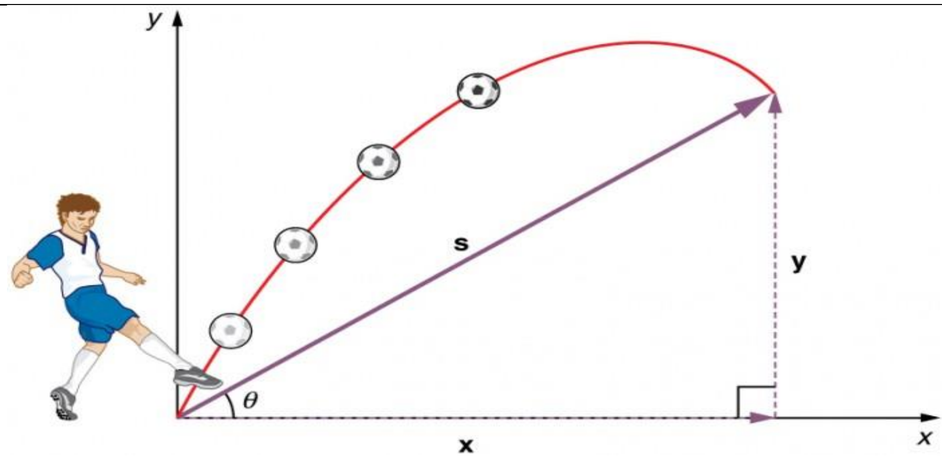
Definition of explosive force. A force represented with separate values for the heat liberated by the explosive decomposition and the detonating rate.

Video



Projectile motion

Projectile motion is a form of motion where an object moves in a bilaterally symmetrical, parabolic path. The path that the object follows is called its trajectory. Projectile motion only occurs when there is one force applied at the beginning on the trajectory, after which the only interference is from gravity. In a previous atom we discussed what the various components of an object in projectile motion are. In this atom we will discuss the basic equations that go along with them in the special case in which the projectile initial positions are null (i.e. x0=0 and y0=0)



Initial Velocity

The initial velocity can be expressed as x components and y components:

$$u_x = u \cdot \cos\theta$$
$$u_y = u \cdot \sin\theta$$

In this equation, u stands for initial velocity magnitude and θ refers to projectile angle.

Time of Flight

The time of flight of a projectile motion is the time from when the object is projected to the time it reaches the surface. As we discussed previously, T
depends on the initial velocity magnitude and the angle of the projectile:

$$T = 2 \cdot u_y / g$$
$$T = 2 \cdot u \cdot \sin\theta / g$$

Acceleration

In projectile motion, there is no acceleration in the horizontal direction. The acceleration, a in the vertical direction is just due to gravity, also known as free fall

$$a_x = 0$$
$$a_y = -g$$

Velocity

The horizontal velocity remains constant, but the vertical velocity varies linearly, because the acceleration is constant. At any time, t and the velocity is:

$$u_x = u \cdot \cos\theta$$

$$u_y = u \cdot \sin\theta - g \cdot t$$

You can also use the Pythagorean Theorem to find velocity: $u = \sqrt{u_x^2 + u_y^2}$

Displacement

At time, t, the displacement components are:

$$x = u \cdot t \cdot \cos\theta$$

$$y = u \cdot t \cdot \sin\theta - 1/2 g t^2$$

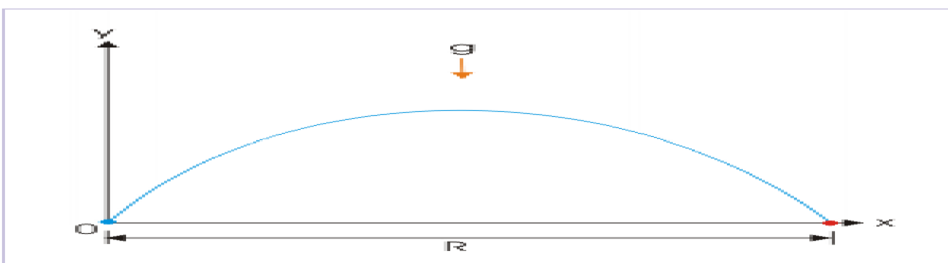
The equation for the magnitude of the displacement is $\Delta r = \sqrt{(x^2 + y^2)}$

Maximum Height

The maximum height is reached when $v_y = 0$
Using this we can rearrange the velocity equation to find the time it will take for the object to reach maximum height
$t_h = u \cdot \sin\theta / g$
where t_h stands for the time it takes to reach maximum height. From the displacement equation we can find the maximum height
$h = u^2 \cdot \sin^2\theta / 2 \cdot g$

Range

The range of the motion is fixed by the condition $y = 0$
Using this we can rearrange the parabolic motion equation to find the range of the motion:
$R = u^2 \cdot \sin 2\theta / g$.



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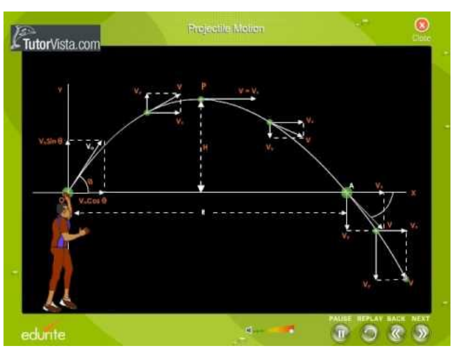
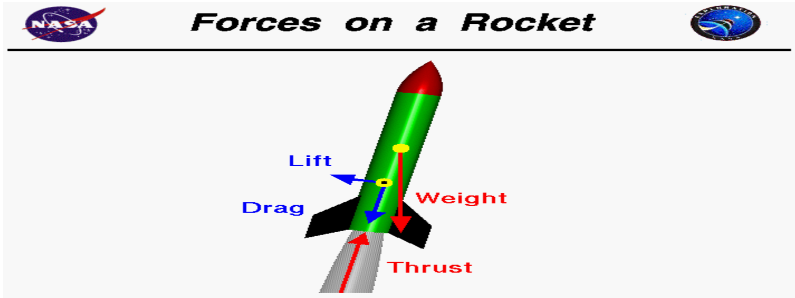


Rocket motion

Rocket motion is based on Newton's third law, which states that "for every action there is an equal and opposite reaction". Hot gases are exhausted through a nozzle of the rocket and produce the action force. The reaction force acting in the opposite direction is called the thrust force.



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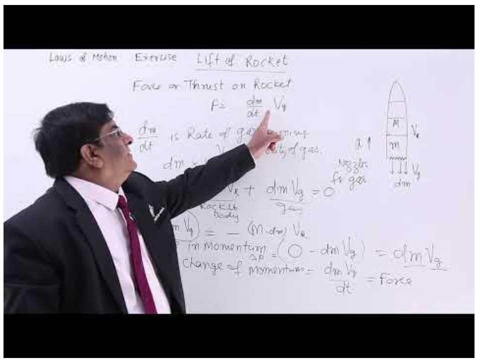

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https://www.google.com/search?source=hp&ei=BZzgXq2wOIiAjLsP64yo0Ac&q=Rocket+motion&oq=Rocket+motion&gs_lcp=CgZwc3ktYWIQAzICCAAyAggAMgIIADICCAAyAggAMgIIADICCAAyAggAMgIIADICCABQzStYzStg9TJoAHAAeACAAfECiAHxApIBAzMtMZgBAKABAqABAaoBB2d3cy13aXo&sclient=psy-ab&ved=0ahUKEwjtxuWl7PbpAhUIAGMBHWsGCnoQ4dUDCAY&uact=5

Learning Objectives

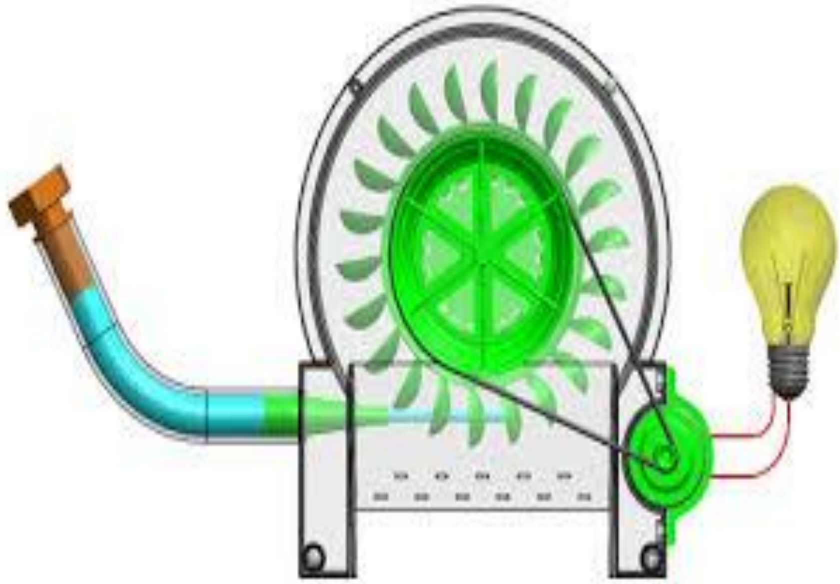
The students will

- Describe vector nature of displacement.
- Describe average and instantaneous velocities of objects.

• Compare average and instantaneous speeds with average and instantaneous velocities.
• Interpret displacement-time and velocity-time graphs of objects moving along the same straight line
• Determine the instantaneous velocity of an object moving along the same straight line by measuring the slope of displacement-time graph.
• Define average acceleration (as rate of change of velocity aav = Δv / Δt) and instantaneous acceleration (as the limiting value of average acceleration when time interval Δt approaches zero).
• Distinguish between positive and negative acceleration, uniform and variable acceleration.
• Determine the instantaneous acceleration of an object measuring the slope of velocity-time graph.
• Manipulate equation of uniformly accelerated motion to solve problems.
• Explain that projectile motion is two-dimensional motion in a vertical plan.
• Communicate the ideas of a projectile in the absence of air resistance that.
(i) Horizontal component (VH) of velocity is constant.
(ii) Acceleration is in the vertical direction and is the same as that of a vertically free falling object.
(iii) The horizontal motion and vertical motion are independent of each other.
• Evaluate using equations of uniformly accelerated motion that for a given initial velocity of frictionless projectile.
1. How higher does it go?
2. How far would it go along the level land?
3. Where would it be after a given time?
4. How long will it remain in air?
• Determine for a projectile launched from ground height.
1. launch angle that results in the maximum range.
2. relation between the launch angles that result in the same range.
• Describe how air resistance affects both the horizontal component and vertical component of velocity and hence the range of the projectile.
• Apply Newton's laws to explain the motion of objects in a variety of context.
• Define mass (as the property of a body which resists change in motion).
• Describe and use of the concept of weight as the effect of a gravitational field on a mass.
• Describe the Newton's second law of motion as rate of change of momentum.
• Co-relate Newton's third law of motion and conservation of momentum.
• Show awareness that Newton's Laws are not exact but provide a good approximation, unless an object is moving close to the speed of light or is small enough that quantum effects become significant.
• Define Impulse (as a product of impulsive force and time).
• Describe the effect of an impulsive force on the momentum of an object, and the effect of lengthening the time, stopping, or rebounding from the collision.
• Describe that while momentum of a system is always conserved in interaction between bodies some change in K.E. usually takes place.
Solve different problems of elastic and inelastic collisions between two bodies in one dimension by using law of conservation of momentum.
• Describe that momentum is conserved in all situations.
• Identify that for a perfectly elastic collision, the relative speed of approach is equal to the relative speed of separation.

Unit-04

Work and Energy



Topic	Understandings	Skills
• Work done by a constant force • Work as scalar product of force and displacement • Work against gravity • Work done by variable force • Gravitational Potential at a point • Escape velocity • Power as scalar product of force and velocity • Work energy principle in resistive medium • Sources and uses of energy Conventional sources of energy	The students will: • Describe the concept of work in terms of the product of force F and displacement d in •The direction of force (Work as scalar product of F and d). • Distinguish between positive, negative and zero work with suitable examples. • Describe that work can be calculated from the area under the force-displacement graph. • Explain gravitational field as an example of field of force and define gravitational field • Strength as force per unit mass at a given point. • Prove that gravitational field is a conservative field. • Compute and show that the work done by gravity as	The students will: • Investigate, at construction sites by comparing a laborer and an electric motor for carrying the bricks to the top of the building. Identify the economy involved. • Investigate that if a ping pong ball is dropped from rest onto a hard plane surface, it usually returns to 75% of its original height after bouncing. What percentage of the energy of the ping pong ball is lost on each bounce? What happens to that energy? • Design an investigation to determine how the efficiency of an electric motor varies with load.

	a mass 'm' is moved from one given point to another does not depend on the path followed. • Describe that the gravitational PE is measured from a reference level and can be positive or negative, to •Denote the orientation from the reference level • Explain the concept of escape velocity in term of gravitational constant G, mass m and radius of planet r. • Differentiate conservative and non-conservative forces giving examples of each. • Express power as scalar product of force and velocity. • Explain that work done against friction is dissipated as heat in the environment. • State the implications of energy losses in practical devices and the concept of efficiency. • Utilize work – energy theorem in a resistive medium to solve problems. • Discuss and make a list of limitations of some conventional sources of energy. • Describe the potentials of some nonconventional sources of energy.	

Science, Technology and Society Connections

The students will:

• Identify, by estimating the cost, benefits of application of scientific principles related, to work and energy in lifting objects by a crane.

• Explain why a car going up a hill requires lower top speed than a car going on theflat.

• Identify energy conversions.

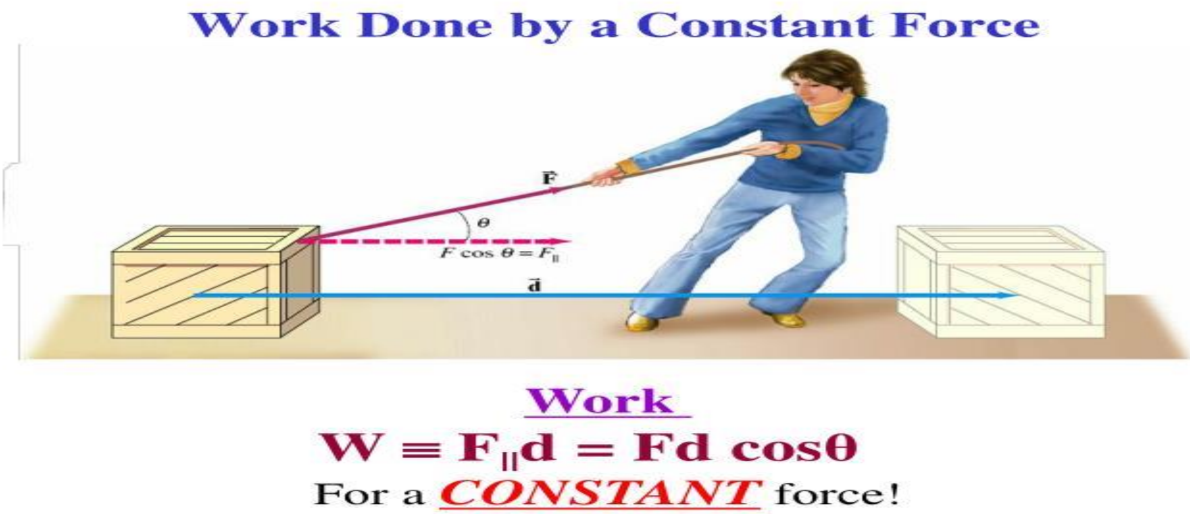
(i) moving car engine

(ii) thermal power station
(iii) Hydroelectric power station
• Investigate and explain how global climate is determined by energy transfer from the Sun and is influenced by a dynamic process (e.g. cloud formation and the earth's rotation) and static conditions (e.g. the position of mountain ranges and oceans)
• Explain how trash can be utilized for producing energy (bio-gas).

Chapter overview

Work done by a constant force

The work done by a constant force can be defined as the product of the displacement of the object (to which the force is applied) and the component of the constant force which is parallel to the direction of displacement. It is important to note that the work done by a constant force is always directly proportional to the product of the magnitude of the applied force and the displacement of the object to which the force was applied.



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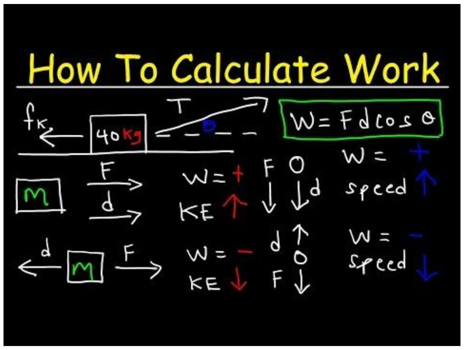


Work as scalar product of force and displacement

A quantity which has only magnitude but no direction is known as a scalar quantity.
Work is done only when a force produces motion. And it is the product of the force exerted on the the body and the distance moved by the body in the direction of force.
i.e. W =F.s
Work is actually the scalar product of force and displacement and hence is a scalar quantity.

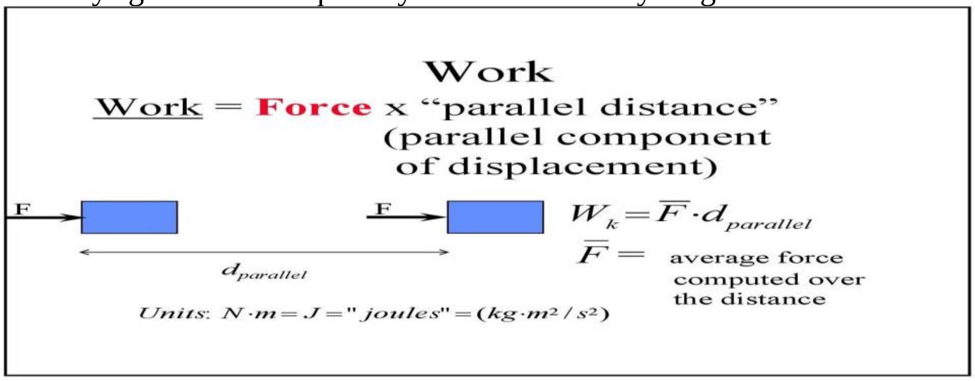
W =F.s

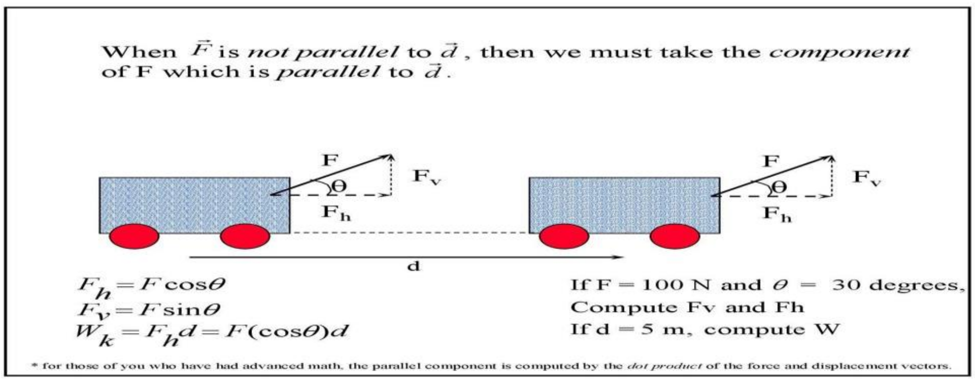
i.e. W = Fs cos θ

where F is the force, s the displacement and θ the angle between force and displacement. According to the angle θ, work can be positive, negative, or zero.

Work is the outcome of the force and displacement caused by the body.

Force and displacement are vector quantities (they have both magnitude and direction) and the dot product of two vector quantites always gives a scalar quantity. So work has only magnitude but not direction.





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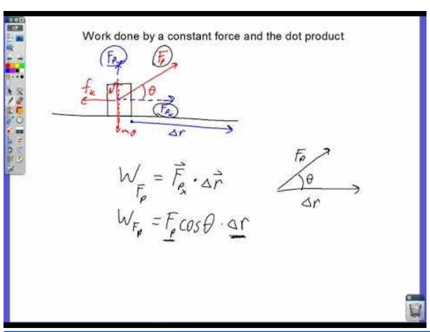
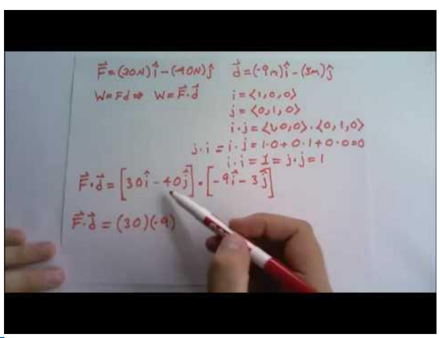
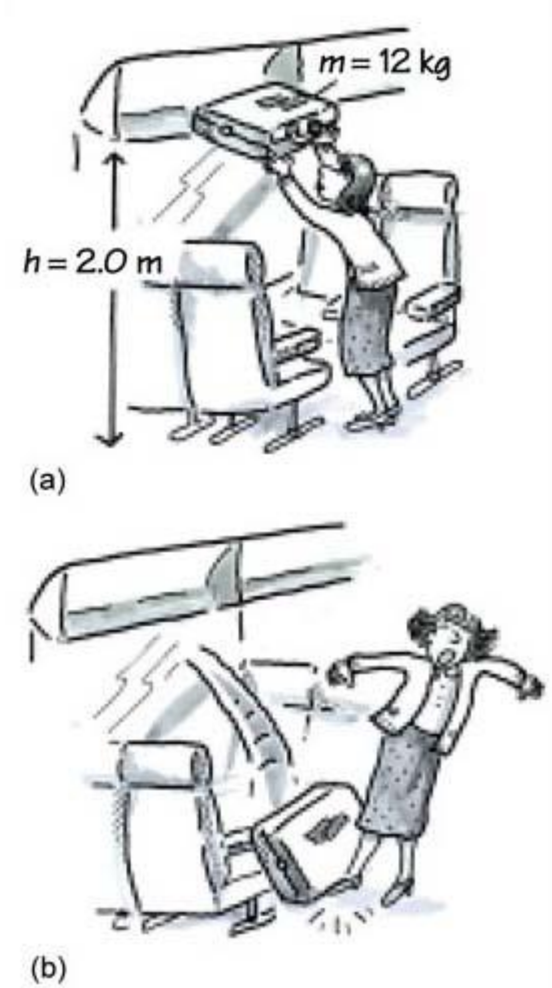




Work against gravity

So far we have only considered objects falling under gravity. Let's now consider the work done when we lift an object. In order to lift an object that has mass *m*, we have to apply an upward force *mg* to overcome the downward force of gravity. If this force raises the object through a height *h*, then the work done is:

$$W = Fd = mg \times h = mgh$$

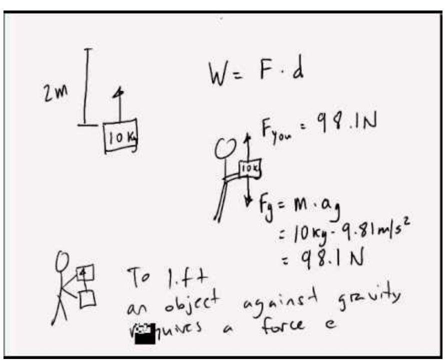


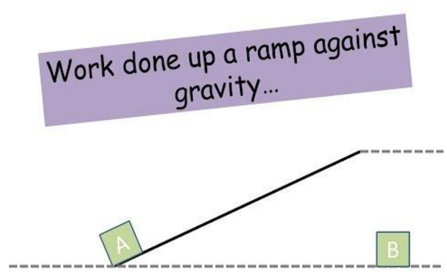
Placing a suitcase on a luggage rack involves doing work against gravity. (b) The stored energy is released if the suitcase falls off the rack.

So if an object of mass *m* is raised through a height *h*, the work done on the object is equal to *mgh*, and so this amount of energy is transferred to the object. (Notice that this equation is identical to the one describing an object falling under gravity,

Of course, this ties in very well with everyday observations. If you lift a heavy suitcase onto a luggage rack in a train, or a heavy bag of shopping onto a table, you are very aware that you are doing work against gravity. You will also be aware that more work is required to lift a more massive object, or the same object to a greater height, and these 'observations' are consistent with the work done being equal to *mgh*.

Videos





Work done by variable force

The area enclosed by the rectangle of length equal to the magnitude of force F(x) and width equal to the displacement Δx, gives the work done by the force during that duration. ... Thus, for a variable force, the work done can be expressed as a definite integral of force over displacement for any system.
So far we have defined work done by a Force which is constant in both magnitude and direction.
However, work can be done by forces that varies in magnitude and direction during the displacement of the body on which it acts.
For simplicity consider the direction of force acting on the body to be along x-axis also consider the force F(x) is some known function of position x
Now total displacement or path of the body can be decomposed into number of small intervals Δx such that with in each interval force F(x) can be considered to be approximately constant as shown below in the figure

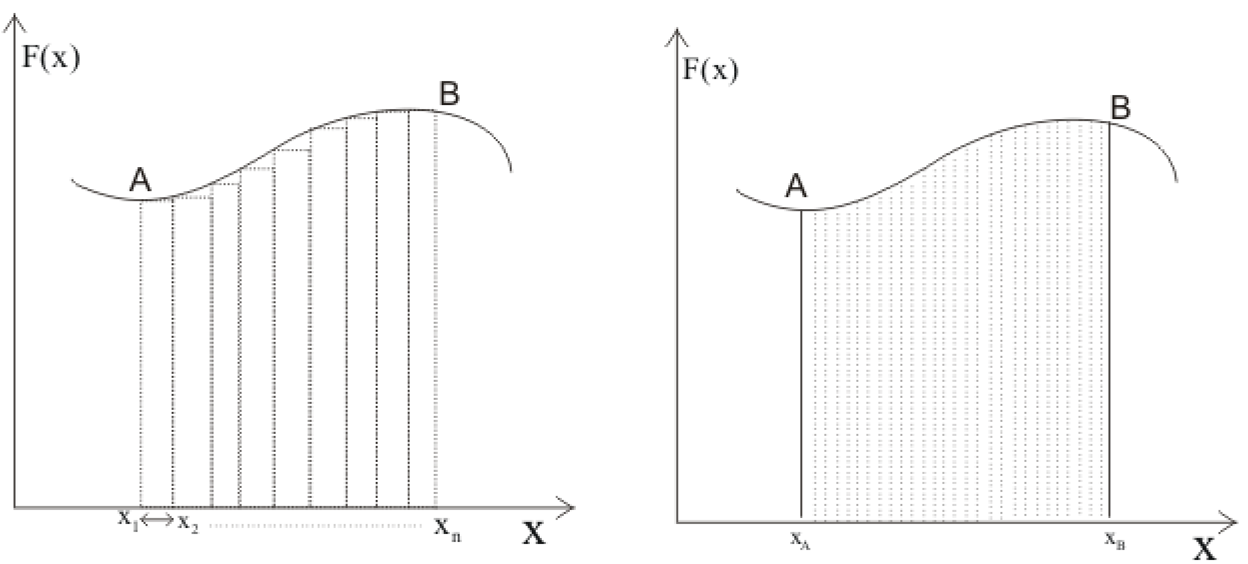


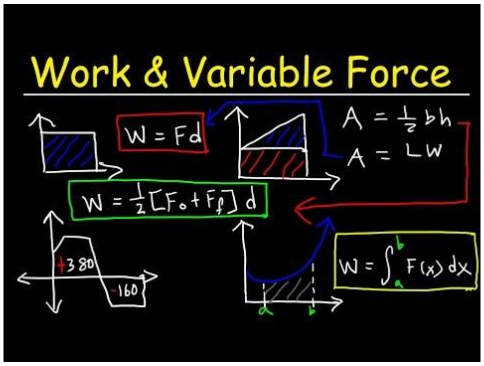
Figure 3. Calculation of work done by variable force F(x) in moving a body from A to B

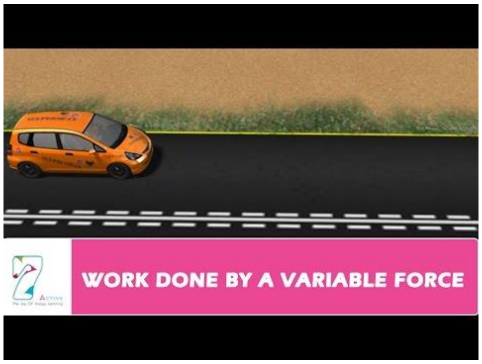
Work done in moving the body from x_1 to x_2 is given by
$\Delta W=F(x_1)\Delta x_1$ where $\Delta x_1=x_2-x_1$
Total work done in moving the body from point A to point B
$W=F(x_1)\Delta x_1 +F(x_2)\Delta x_2 +F(x_3)\Delta x_3 .....+F(x_n)\Delta x_n$
$W=\Sigma F(x_i)\Delta x_i$ where i=1 to i=n (4)
Where Σ is the symbol of summation
Summation in equation 4 is equal to shaded area in figure 3(a) .More accuracy of results can be obtained by making these interval infinitesimally smaller
We get the exact value of work done by making each interval so much small such that #916;x-> 0 which means curved path being decomposed into infinite number of line segment i.e
$W= \text{Lim}_{\Delta x\to 0}\Sigma F(x_i)\Delta x_i$ (5)
W=∫xbxafdx Where ∫xbxafdx
The integral of F(x) w.r.t x between the limits x_A and x_B and integral can be evaluated using methods of calculus if F(x) of x is known
Instead of x if the force also acts along y and z axis i.e direction of force keeps on changing then work done by such a force is given by

$W=\int F(r)dr$ with in the limits r_A and r_B (6)
Where $F(r)=F(x)i +F(y)j+ F(z)k$
and $dr=dxi +dyj+ dzk$

Here F(x),F(y) and F(z) are rectangular components of the force along x ,y and z axis .Similarly dx,dy and dz are rectangular components of displacement along
x ,y and z axis
Work done by the variable force along x-axis can also be calculated using the graphical way also. The area enclosed by the Force displacement gives the work done by the variable force

Videos



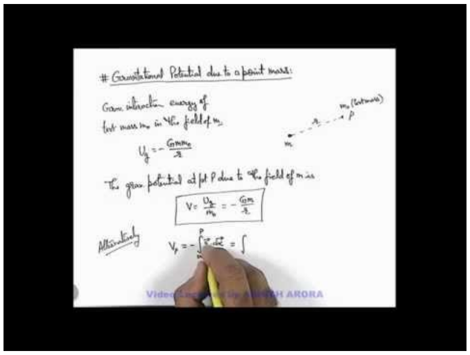


Gravitational Potential at a point

The gravitational potential at a point in a gravitational field is the work done per unit mass that would have to be done by some externally applied force to bring a massive object to that point from some defined position of zero potential, usually infinity. It is the gravitational potential difference between the chosen point and the position of zero potential.
Gravitational potential is often represented by the symbol *V*.
If the field is due to an isolated massive point object (or any object of finite size), then it is conventional to define the potential to be zero at an infinite distance from the object; the potential is negative everywhere else because the gravitational force is always attractive.
Gravitational potential is also defined as the gravitational potential energy per unit mass relative to a defined position of zero potential energy. The two definitions are equivalent.
Discussion
There is a strong similarity between gravitational potential and electrostatic potential. In both cases, the underlying forces depend on the separation, *r*, of interacting objects as $1r^2$ and, in both cases, the change in the potential is defined via the work done in changing the separation between the interacting objects. The difference lies in the nature of the force: charges may be positive or negative, so the electrostatic interaction may be attractive or repulsive. The force of gravity is always attractive.
SI unit
$J\ kg^{-1}$
Expressed in SI base units
$m^2\ s^{-2}$
Other commonly used unit(s)
none
Mathematical expressions
Raising an object through a height Δh at the surface of the Earth leads to a change of gravitational potential
$\Delta V = g\Delta h$
where g is the gravitational field at the surface of the Earth and Δh is much less than the radius of the Earth.
More generally,
$\Delta V = GM\mathrm{R} - GM\mathrm{R}+\Delta h = GM\mathrm{R}\ \Delta hR+\Delta h$
where *M* and *R* are, respectively, the mass and radius of the Earth, and *G* is the universal gravitational constant.
Related entries

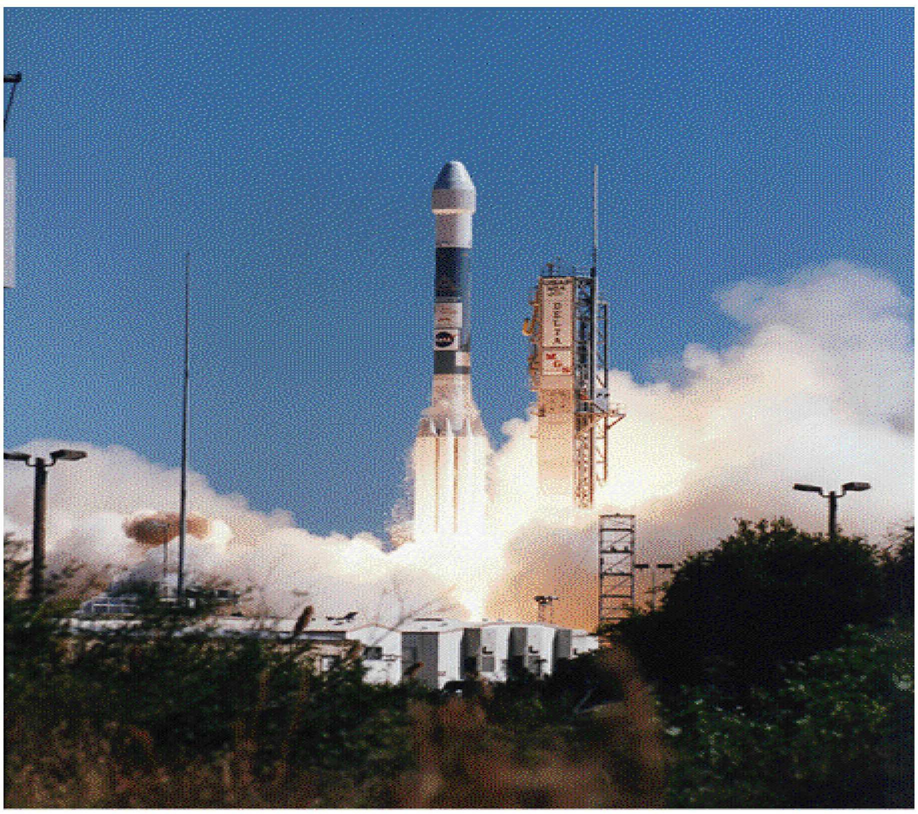
Gravitational field
Potential energy
In context
The difference in gravitational potential between sea level and the summit of Mount Everest is about 8.7×10^4 J kg^{-1}. If a mountaineer of mass 100 kg travels from sea level to the Everest summit, the gravitational potential energy of the Earth-mountaineer system increases by about 8.7×10^6 J.

Video



Escape velocity

Escape velocity is the speed that an object needs to be traveling to break free of a planet or moon's gravity well and leave it without further propulsion. For example, a spacecraft leaving the surface of Earth needs to be going 7 miles per second, or nearly 25,000 miles per hour to leave without falling back to the surface or falling into orbit.



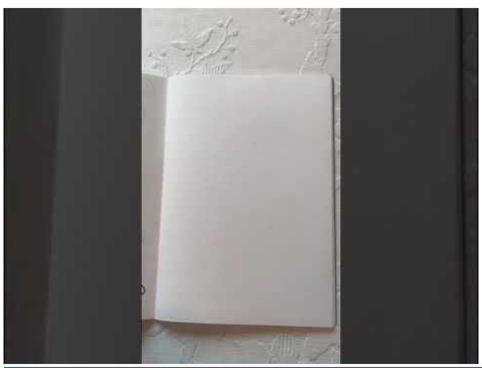
A Delta II rocket blasting off. A large amount of energy is needed to achieve escape velocity. *Photo from Jet Propulsion Laboratory's Planetary Missions & Instruments image gallery*

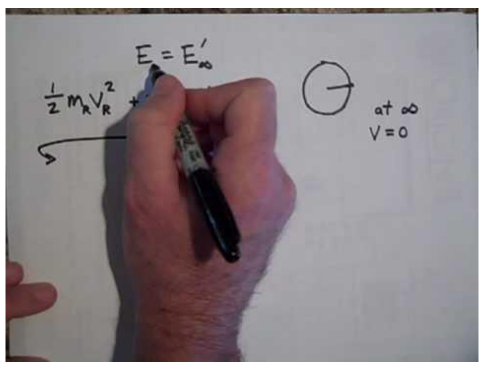
Since escape velocity depends on the mass of the planet or moon that a spacecraft is blasting off of, a spacecraft leaving the moon's surface could go slower than one blasting off of the Earth, because the moon has less gravity than the Earth. On the other hand, the escape velocity for Jupiter would be many times that of Earth's because Jupiter is so huge and has so much gravity.

Body	Mass	Escape Velocity in Kilometers/ Second	Escape Velocity in Miles/Hour
Ceres (largest asteroid in the asteroid belt)	1,170,000,000,000,000,000 kg	.64 km/sec	1430.78 mph
The Moon	73,600,000,000,000,000,000 kg	2.38 km/sec	5320.73 mph
Earth	5,980,000,000,000,000,000,000 kg	11.2 km/sec	25038.72 mph
Jupiter	715,000,000,000,000,000,000,000,000 kg	59.5 km/sec	133018.2 mph
Sun	1,990,000,000,000,000,000,000,000,000 kg	618. km/sec	1381600.8 mph
Sirius B (a white dwarf star)	2,000,000,000,000,000,000,000,000,000 kg	5,200. km/sec	11625120 mph

One reason that manned missions to other planets are difficult to plan is that a ship would have to take enough fuel into space to blast off of the other planet when the astronauts wanted to go home. The weight of the fuel would make the spaceship so heavy it would be hard to blast it off of Earth!

Videos





Power as scalar product of force and velocity

Power may be defined as the rate of doing work or the rate of using energy. These two definitions are equivalent since one unit of energy must be used to do one unit of work. Often it is convenient to calculate the average power.

$$P_{avg} = \frac{Work}{time} = \frac{F\cos\theta\ x}{t}$$ Calculation

This can be rearranged in the form:

$$P_{avg} = F\cos\theta\ v_{avg}$$

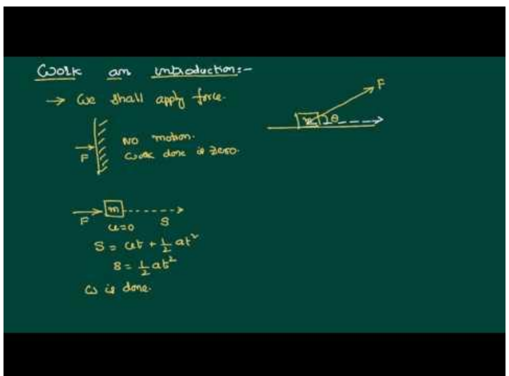
It turns out that this is a general form and that instantaneous power can be calculated from the expression:

$$P_{instantaneous} = F\cos\theta\ v$$

which in vector notation is the scalar product: $P = \vec{F}\cdot\vec{v}$

In the straightforward cases where a constant force moves an object at constant velocity, the power is just P = Fv. In a more general case where the velocity is not in the same direction as the force, then the scalar product of force and velocity must be used.
The standard unit for power is the watt (abbreviated W) which is a joule per second

Video

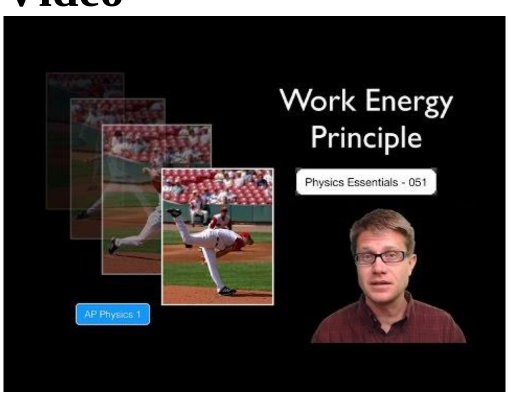


Work energy principle

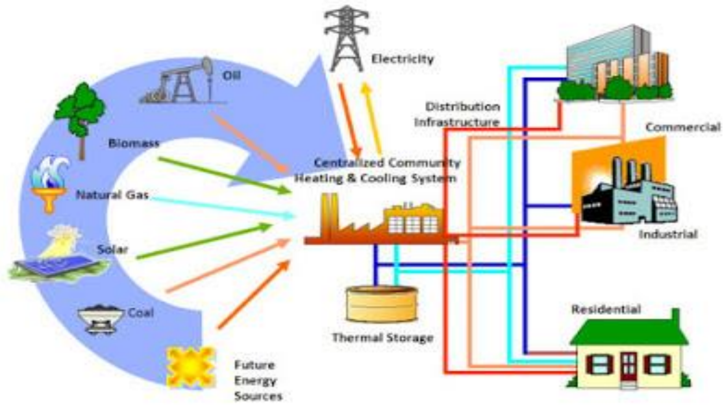
The work-energy principle states that

"An increase in the kinetic energy of a rigid body is caused by an equal amount of positive work done on the body by the resultant force acting on that body. Conversely, a decrease in kinetic energy is caused by an equal amount of negative work done by the resultant force."

Video



Sources and uses of energy



1. Solar Energy

Solar power harvests the energy of the sun through using collector panels to create conditions that can then be turned into a kind of power. Large solar panel fields are often used in desert to gather enough power to charge small substations, and many homes use solar systems to provide for hot water, cooling and supplement their electricity. The issue with solar is that while there is plentiful amounts of sun available, only certain geographical ranges of the world get enough of the direct power of the sun for long enough to generate usable power from this source.

2. Wind Energy

Wind power is becoming more and more common. The new innovations that are allowing wind farms to appear are making them a more common sight. By using large turbines to take available wind as the power to turn, the turbine can then turn a generator to produce electricity. While this seemed like an ideal solution to many, the reality of the wind farms is starting to reveal an unforeseen ecological impact that may not make it an ideal choice.

3. Geothermal Energy

Geothermal energy is the energy that is produced from beneath the earth. It is clean, sustainable and environment friendly. High temperatures are produced continuously inside the earth's crust by the slow delay of radioactive particles. Hot rocks present below the earth heats up the water that produces steam. The steam is then captured that helps to move turbines. The rotating turbines then power the generators. Geothermal energy can be used by a residential unit or on a large scale by a industrial application. It was used during ancient times for bathing and space heating. The biggest disadvantage with geothermal energy is that it can only be produced at selected sites throughout the world. The largest group of geothermal power plants in the world is located at The Geysers, a geothermal field in California, United States.

4. Hydrogen Energy

Hydrogen is available with water(H2O) and is most common element available on earth. Water contains two-thirds of hydrogen and can be found in combination with other elements. Once it is separated, it can be used as a fuel for generating electricity. Hydrogen is a tremendous source of energy and can be used as a source of fuel to power ships, vehicles, homes, industries and rockets. It is completely renewable, can be produced on demand and does not leave any toxic emissions in the atmosphere.

5. Tidal Energy

Tidal energy uses rise and fall of tides to convert kinetic energy of incoming and outgoing tides into electrical energy. The generation of energy through tidal power is mostly prevalent in coastal areas. Huge investment and limited availability of sites are few of the drawbacks of tidal energy. When there is increased height of water levels in the ocean, tides are produced which rush back and forth in the ocean. Tidal energy is one of the renewable source of energy and produce large energy even when the tides are at low speed.

6. Wave Energy

Wave energy is produced from the waves that are produced in the oceans. Wave energy is renewable, environment friendly and causes no harm to atmosphere. It can be harnessed along coastal regions of many countries and can help a country to reduce its dependance on foreign countries for fuel. Producing wave energy can damage marine ecosystem and can also be a source of disturbance to private and commercial vessels. It is highly dependent on wavelength and can also be a source of visual and noise pollution.

7. Hydroelectric Energy

What many people are not aware of is that most of the cities and towns in the world rely on hydropower, and have for the past century. Every time you see a major dam, it is providing hydropower to an electrical station somewhere. The power of the water is used to turn generators to produce the electricity that is then used. The problems faced with hydropower right now have to do with the aging of the dams. Many of them need major restoration work to remain functional and safe, and that costs enormous sums of money. The drain on the world's drinkable water supply is also causing issues as townships may wind up needing to consume the water that provides them power too.

8. Biomass Energy

Biomass energy is produced from organic material and is commonly used throughout the world. Chlorophyll present in plants captures the sun's energy by converting carbon dioxide from the air and water from the ground into carbohydrates through the process of photosynthesis. When the plants are burned, the water and carbon dioxide is again released back into the atmosphere. Biomass generally include crops, plants, trees, yard clippings, wood chips and animal wastes. Biomass energy is used for heating and cooking in homes and as a fuel in industrial production. This type of energy produces large amount of carbon dioxide into the atmosphere.

9. Nuclear Power

While nuclear power remains a great subject of debate as to how safe it is to use, and whether or not it is really energy efficient when you take into account the waste it produces – the fact is it remains one of the major renewable sources of energy available to the world. The energy is created through a specific nuclear reaction, which is then collected and used to power generators. While almost every country has nuclear generators, there are moratoriums on their use or construction as scientists try to resolve safety and disposal issues for waste.

10. Fossil Fuels (Coal, Oil and Natural Gas)

When most people talk about the different sources of energy they list natural gas, coal and oil as the options – these are all considered to be just one source of energy from fossil fuels. Fossil fuels provide the power for most of the world, primarily using coal and oil. Oil is converted into many products, the most used of which is gasoline. Natural gas is starting to become more common, but is used mostly for heating applications although there are more and more natural gas-powered vehicles appearing on the streets. The issue with fossil fuels is twofold. To get to the fossil fuel and convert it to use there has to be a heavy destruction and pollution of the environment. The fossil fuel reserves are also limited, expecting to last only another 100 years given are basic rate of consumption.

It isn't easy to determine which of these different sources of energy is best to use. All of them have their good and bad points. While advocates of each power type tout theirs as the best, the truth is that they are all flawed. What needs to happen is a concerted effort to change how we consume energy and to create a balance between which of these sources we draw from.

Video

Conventional sources of Energy

When we cannot reuse a source of energy after using it once we call them “conventional sources of energy” or “non-renewable energy resources”. They are the most important conventional sources of energy. These include coal, petroleum, natural gas and nuclear energy. Oil is the most widely used source of energy.

‘Always surround yourself with positive energy’. You must have heard this phrase quite a lot; what is this energy we’re talking about? Do things have energy in them? And are these things conventional sources of energy? But, before that what are conventional sources of energy? How do we obtain this energy? Since all living beings use energy for various vital activities inside as well as outside their body. So, let us study about various conventional sources of energy

Video

Reference Page

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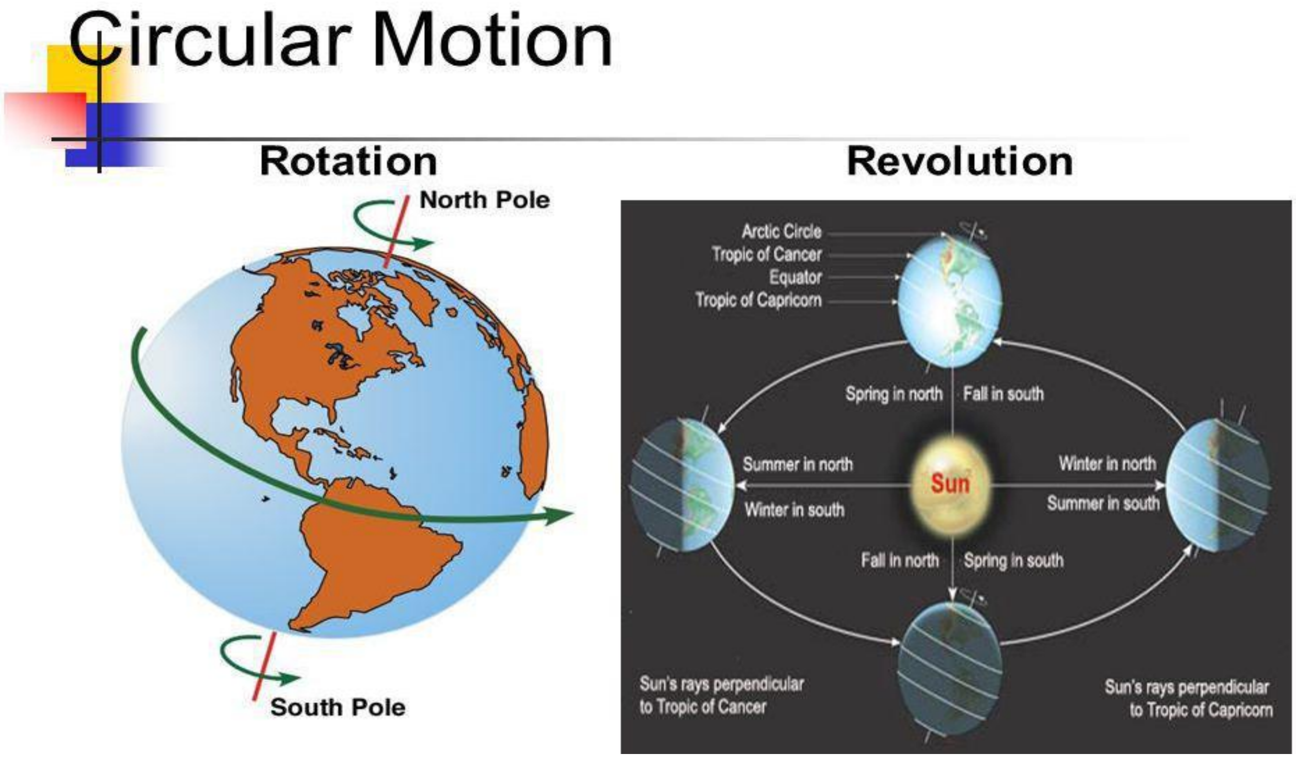
Unit 05

Rotational and Circular Motion



Topics	Understandings	Skills
• Kinematics of angular motion • Centripetal force and centripetal acceleration • Orbital velocity • Artificial satellites • Artificial gravity • Moment of inertia • Angular momentum	The students will: • Define angular displacement, angular velocity and angular acceleration and express angular displacement in radians. • Solve problems by using $S = r\theta$ and $v = r\omega$. • State and use of equations of angular motion to solve problems involving rotational motions. • Describe qualitatively motion in a curved path due to a perpendicular force. • Derive and use centripetal acceleration $a = r\omega^2$, $a = v^2/r$. • Solve problems using centripetal force $F = mr\omega^2$, $F = mv^2/r$. • Describe situations in which the centripetal acceleration is caused by a tension force, a frictional force, a gravitational force, or a norma force.	The students will: • Demonstrate the conservation of angular momentum by spinning stool and dumbles (weights). • Demonstrate the action of a centrifuge e.g. washing machine dryer. • Determine the moment of inertia of a fly wheel.

	• Explain when a vehicle travels round a banked curve at the specified speed for the banking angle, the horizontal component of the normal force on the vehicle causes the centripetal acceleration. • Describe the equation tanθ = v2/rg, relating banking angle θ to the speed v of the vehicle and the radius of curvature r. • Explain that satellites can be put into orbits round the earth because of the gravitational force between the earth and the satellite. • Explain that the objects in orbiting satellites appear to be weightless. • Describe how artificial gravity is created to counter balance weightless. • Define the term orbital velocity and derive relationship between orbital velocity, the gravitational constant, mass and the radius of the orbit. • Analyze that satellites can be used to send information between places on the earth which are far apart, to monitor conditions on earth , including the weather, and to observe the universe without the atmosphere getting in the way. • Describe that communication satellites are usually put into orbit high above the equator and that they orbit the earth once a day so that they appear stationary when viewed from earth. • Define moment of inertia of a body and angular momentum. • Derive a relation between torque, moment of inertia and angular acceleration. • Explain conservation of angular momentum as a universal law and describe examples of conservation of angular momentum. • Use the formulae of moment of inertia of various bodies for solvingproblems.	

Science, Technology and Society Connections

The students will:

• Assess the suitability of the recommended speed limit for the given data on the banking angle and radius of curvature of some roads.
• Describe the experience of roller coaster rides in the amusement parks.
• Describe the principles and benefits of weather forecasting and communication satellites.
• Evaluate the accuracy of the information presented in a newspaper article on satellite.
• write a report on an information search on the topic of 'space station'

Chapter overview

Kinematics of angular motion

Angular kinematics is the study of rotational motion in the absence of forces. The equations of angular kinematics are extremely similar to the usual equations of kinematics, with quantities like displacements replaced by angular displacements and velocities replaced by angular velocities. Just as kinematics is routinely used to describe the trajectory of almost any physical system moving linearly, the equations of angular kinematics are relevant to most rotating physical systems.

Basic Equations of Angular Kinematics

In purely rotational (circular) motion, the equations of angular kinematics are:

$$v=r\omega, \quad ac=-r\omega^2 \quad ,a=r\alpha$$

The tangential velocity v describes the velocity of an object tangent to its path in rotational motion at angular frequency ω and radius r. This is the velocity an object would follow if it suddenly broke free of rotational motion and traveled along a straight line. The rate of change of this velocity is the tangential acceleration a. The centripetal acceleration a_c is a second acceleration experienced by rotating objects, because changing the direction of a velocity vector requires an acceleration. Since the direction of the velocity vector changes constantly in rotational motion, rotating objects must be continuously accelerated towards the axis of rotation by some force providing a centripetal acceleration.
From the above equations, the usual kinematic equations hold in angular form. If an object under goes constant angular acceleration α\alphaα, the total angular displacement is:

$$\theta-\theta_0=W_0t+1/2\alpha t^2$$

where θ_0 is the initial angle and W_0 is the initial angular velocity. Similarly, the angular velocity changes according to:

$$\omega^2= W_0^2+2\alpha(\theta-\theta_0)$$

in terms of the angular displacement, or

$$\omega= W_0+\alpha t$$

in terms of time.
Though the above derivation gives the magnitudes of angular quantities correctly, it does not capture the fact that angular quantities are *also* vector quantities. The direction in which the angular velocity points can be found from the right-hand rule: curving the fingers of your right hand along the direction of rotation, your thumb points in the direction of the angular velocity vector, along the axis of rotation. This is true by definition; although it seems strange since the vector is perpendicular to the rotation, this definition turns out to be the only way to formulate a consistent vector theory of rotational forces.

Centripetal force and centripetal acceleration

What is a centripetal force?

A centripetal force is a net force that acts on an object to keep it moving along a circular path.
Centripetal acceleration, we learned that any object traveling along a circular path of radius r with velocity v experiences an acceleration directed toward the center of its path,

$$a_c= v^2/r$$

However, we should discuss how the object came to be moving along the circular path in the first place. Newton's 1st law tells us that an object will continue moving along a straight path unless acted on by an external force. The external force here is the centripetal force.
It is important to understand that the centripetal force is not a fundamental force, but just a label given to the net force which causes an object to move in a circular path. The tension force in the string of a swinging

tethered ball and the gravitational force keeping a satellite in orbit are both examples of centripetal forces. Multiple individual forces can even be involved as long as they add up (by vector addition) to give a net force towards the center of the circular path.
Starting with Newton's 2nd law :

$$a=F/m$$

and then equating this to the centripetal acceleration,

$$v^2/r= F/m$$

We can show that the centripetal force Fc

$$Fc=mv^2/r$$

and is always directed towards the center of the circular path. Equivalently, if w is the angular velocity then because v=rω

$$Fc=mrw^2$$

Videos

Orbital velocity

In gravitationally bound systems, the orbital speed of an astronomical body or object (e.g. planet, moon, artificial satellite, spacecraft, or star) is the speed at which it orbits around either the barycenter or, if one object is much more massive than the other bodies in the system, its speed relative to the center of mass of the most massive body.
The term can be used to refer to either the mean orbital speed, i.e. the average speed over an entire orbit, or its instantaneous speed at a particular point in its orbit. Maximum (instantaneous) orbital speed occurs at periapsis (perigee, perihelion, etc.), while minimum speed for objects in closed orbits occurs at apoapsis (apogee, aphelion, etc.). In ideal two-body systems, objects in open orbits continue to slow down forever as their distance to the barycenter increases.
When a system approximates a two-body system, instantaneous orbital speed at a given point of the orbit can be computed from its distance to the central body and the object's specific orbital energy, sometimes called "total energy". Specific orbital energy is constant and independent of position.

Radial trajectories

In the following, it is assumed that the system is a two-body system and the orbiting object has a negligible mass compared to the larger (central) object. In real-world orbital mechanics, it is the system's barycenter, not the larger object, which is at the focus.
Specific orbital energy, or total energy, is equal to K.E. − P.E. (kinetic energy − potential energy). The sign of the result may be positive, zero, or negative and the sign tells us something about the type of orbit.
If the specific orbital energy is positive the orbit is unbound, or open, and will follow a hyperbola with the larger body the focus of the hyperbola. Objects in open orbits do not return; once past periapsis their distance from the focus increases without bound. See radial hyperbolic trajectory
If the total energy is zero, (K.E = P.E.): the orbit is a parabola with focus at the other body. See radial parabolic trajectory. Parabolic orbits are also open.

If the total energy is negative, K.E. − P.E. < 0: The orbit is bound, or closed. The motion will be on an ellipse with one focus at the other body. See radial elliptic trajectory, free-fall time. Planets have bound orbits around the Sun.

Transverse orbital speed

The transverse orbital speed is inversely proportional to the distance to the central body because of the law of conservation of angular momentum, or equivalently, Kepler's second law. This states that as a body moves around its orbit during a fixed amount of time, the line from the barycenter to the body sweeps a constant area of the orbital plane, regardless of which part of its orbit the body traces during that period of time.

This law implies that the body moves slower near its apoapsis than near its periapsis, because at the smaller distance along the arc it needs to move faster to cover the same area.

Mean orbital speed

For orbits with small eccentricity, the length of the orbit is close to that of a circular one, and the mean orbital speed can be approximated either from observations of the orbital period and the semimajor axis of its orbit, or from knowledge of the masses of the two bodies and the semimajor axis.

$$V=2\pi a/T=\sqrt{\frac{u}{a}}$$

where v is the orbital velocity, a is the length of the semimajor axis in meters, T is the orbital period, and $\mu=GM$ is the standard gravitational parameter. This is an approximation that only holds true when the orbiting body is of considerably lesser mass than the central one, and eccentricity is close to zero.

When one of the bodies is not of considerably lesser mass see: Gravitational two-body problem

So, when one of the masses is almost negligible compared to the other mass, as the case for Earth and Sun, one can approximate the orbit velocity as:

$$V=\sqrt{\frac{GM}{r}}$$

or assuming r equal to the body's radius

$$V_0=V_e/\sqrt{2}$$

Where M is the (greater) mass around which this negligible mass or body is orbiting, and v_e is the escape velocity.

For an object in an eccentric orbit orbiting a much larger body, the length of the orbit decreases with orbital eccentricity e, and is an ellipse. This can be used to obtain a more accurate estimate of the average orbital speed:

$$v_o=\frac{2\pi a}{T}\left[1-\frac{1}{4}e^2-\frac{3}{64}e^4-\frac{5}{256}e^6-\frac{175}{16384}e^8-\dots\right]$$ [4]

The mean orbital speed decreases with eccentricity.

Instantaneous orbital speed

For the instantaneous orbital speed of a body at any given point in its trajectory, both the mean distance and the instantaneous distance are taken into account

$$v=\sqrt{\mu\left(\frac{2}{r}-\frac{1}{a}\right)}$$

where μ is the standard gravitational parameter of the orbited body, r is the distance at which the speed is to be calculated, and a is the length of the semi-major axis of the elliptical orbit. This expression is called the vis-viva equation.

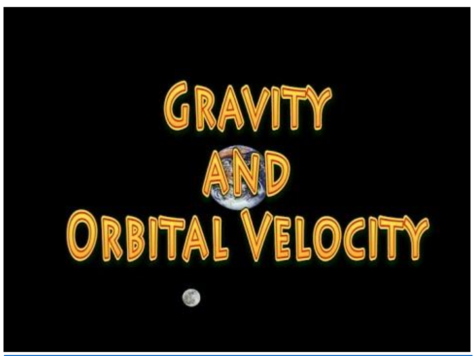
For the Earth at perihelion, the value is:

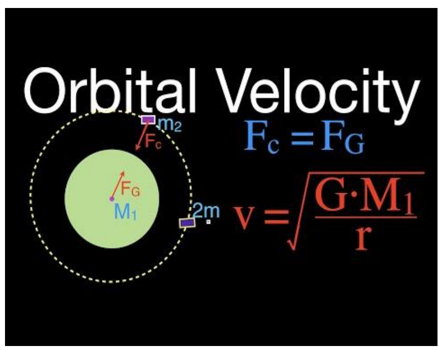
$$\sqrt{1.327 \times 10^{20}\ \mathrm{m^3 s^{-2}} \cdot \left(\frac{2}{1.471 \times 10^{11}\ \mathrm{m}} - \frac{1}{1.496 \times 10^{11}\ \mathrm{m}}\right)} \approx 30,300\ \mathrm{m/s}$$

which is slightly faster than Earth's average orbital speed of 29,800 m/s, as expected from Kepler's 2nd Law

Orbit	Center-to-center distance	Altitude above the Earth's surface	Speed	Orbital period	Specific orbital energy
Earth's own rotation at surface (for comparison— not an orbit)	*6,378 km*	*0 km*	*465.1 m/s (1,674 km/h or 1,040 mph)*	*23 h 56 min*	*−62.6 MJ/kg*
Orbiting at Earth's surface (equator)	6,378 km	0 km	7.9 km/s (28,440 km/h or 17,672 mph)	1 h 24 min 18 sec	−31.2 MJ/kg
Low Earth orbit	6,600–8,400 km	200–2,000 km	Circular orbit: 6.9–7.8 km/s (24,840–28,080 km/h or 14,430–17,450 mph) respectively Elliptic orbit: 6.5–8.2 km/s respectively	1 h 29 min – 2 h 8 min	−29.8 MJ/kg
Molniya orbit	6,900–46,300 km	500–39,900 km	1.5–10.0 km/s (5,400–36,000 km/h or 3,335–22,370 mph) respectively	11 h 58 min	−4.7 MJ/kg
Geostationary	42,000 km	35,786 km	3.1 km/s (11,600 km/h or 6,935 mph)	23 h 56 min	−4.6 MJ/kg
Orbit of the Moon	363,000–406,000 km	357,000–399,000 km	0.97–1.08 km/s (3,492–3,888 km/h or 2,170–2,416 mph) respectively	27.3 days	−0.5 MJ/kg

Video





Artificial satellites

A satellite is an object in space that orbits or circles around a bigger object. There are two kinds of satellites: natural (such as the moon orbiting the Earth) or artificial (such as the International Space Station orbiting the Earth).

There are dozens upon dozens of natural satellites in the solar system, with almost every planet having at least one moon. Saturn, for example, has at least 53 natural satellites, and between 2004 and 2017, it also had an artificial one — the Cassini spacecraft, which explored the ringed planet and its moons.

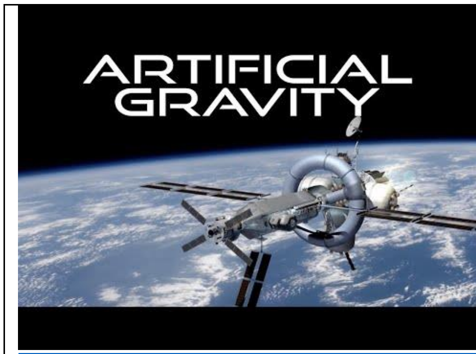
Artificial satellites, however, did not become a reality until the mid-20th century. The first artificial satellite was Sputnik, a Russian beach-ball-size space probe that lifted off on Oct. 4, 1957. That act shocked much of the western world, as it was believed the Soviets did not have the capability to send satellites into space

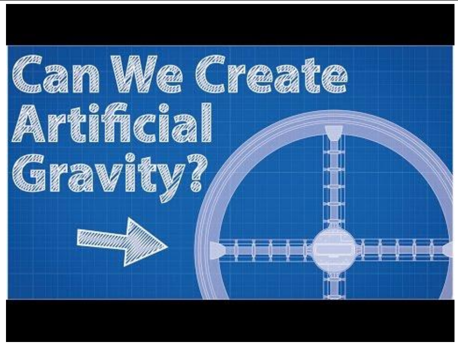
Video

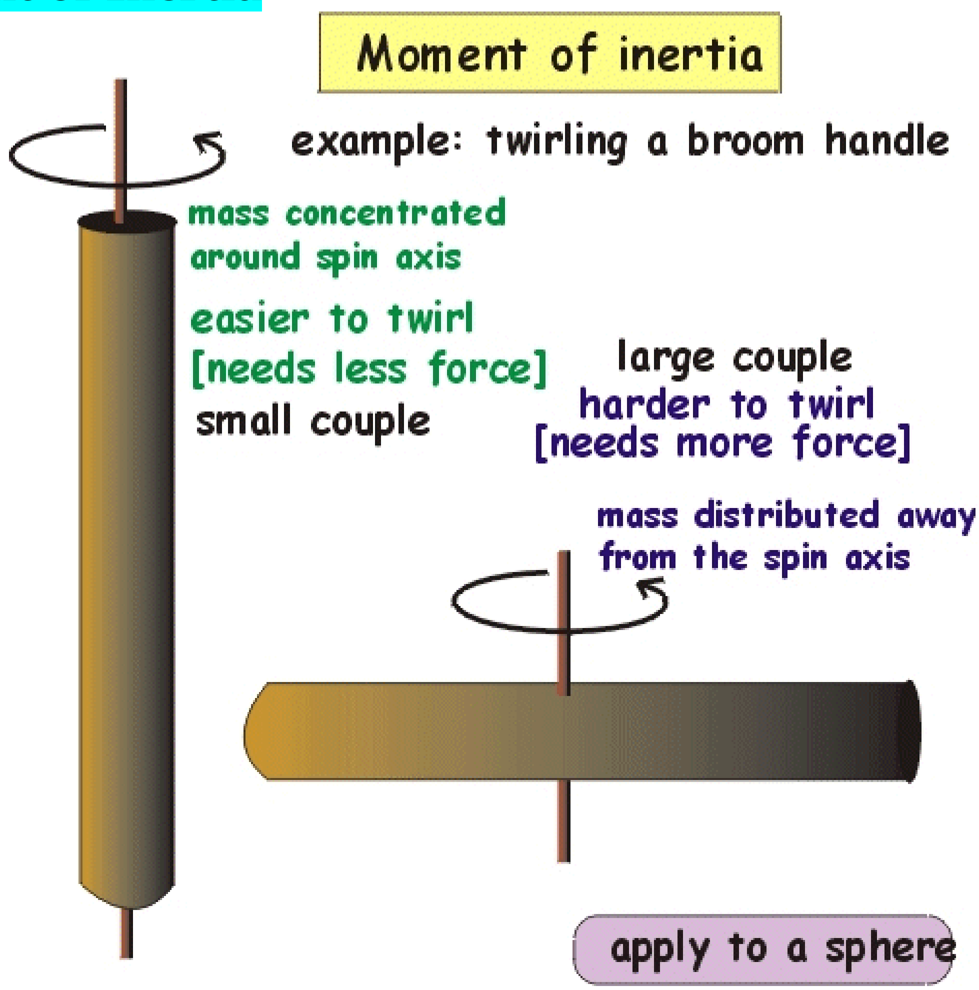
Artificial gravity (sometimes referred to as pseudo gravity) is the creation of an inertial force that mimics the effects of a gravitational force, usually by rotation. Artificial gravity, or rotational gravity, is thus the appearance of a centrifugal force in a rotating frame of reference (the transmission of centripetal acceleration via normal force in the non-rotating frame of reference), as opposed to the force experienced in linear acceleration, which by the equivalence principle is indistinguishable from gravity. In a more general sense, "artificial gravity" may also refer to the effect of linear acceleration, e.g. by means of a rocket engine. Rotational simulated gravity has been used in simulations to help astronauts train for extreme conditions. Rotational simulated gravity has been proposed as a solution in human spaceflight to the adverse health effects caused by prolonged weightlessness. However, there are no current practical outer space applications of artificial gravity for humans due to concerns about the size and cost of a spacecraft necessary to produce a useful centripetal force comparable to the gravitational field strength on Earth

Videos

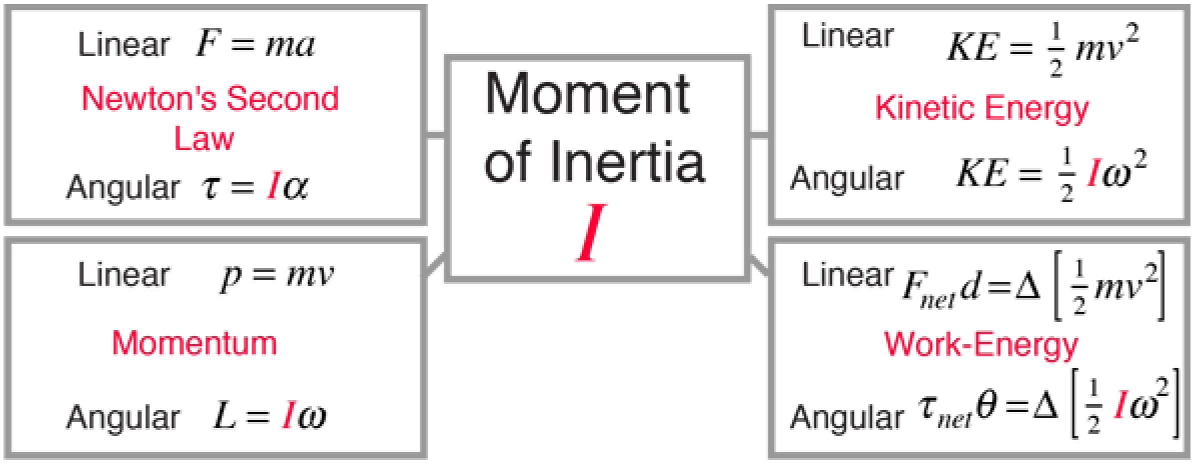




Moment of Inertia



Moment of inertia is the name given to rotational inertia, the rotational analog of <u>mass</u> for linear motion. It appears in the relationships for the dynamics of rotational motion. The moment of inertia must be specified with respect to a chosen axis of rotation. For a <u>point mass</u>, the moment of inertia is just the mass times the square of perpendicular distance to the rotation axis, $I = mr^2$. That point mass relationship becomes the basis for all other moments of inertia since any object can be built up from a collection of point masses.



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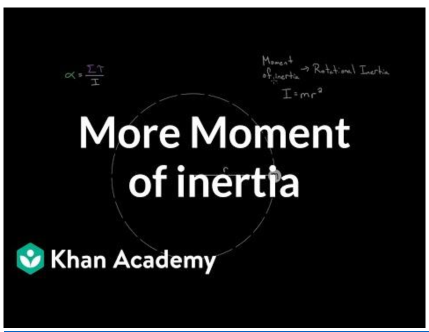
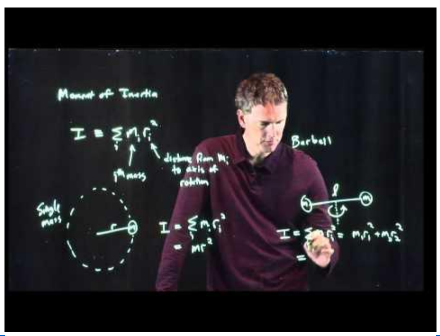
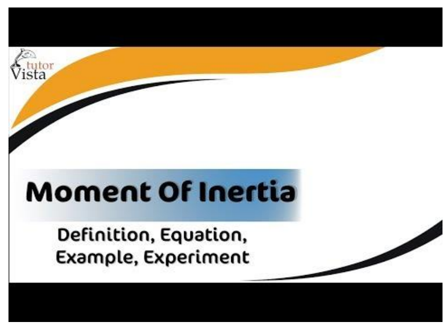
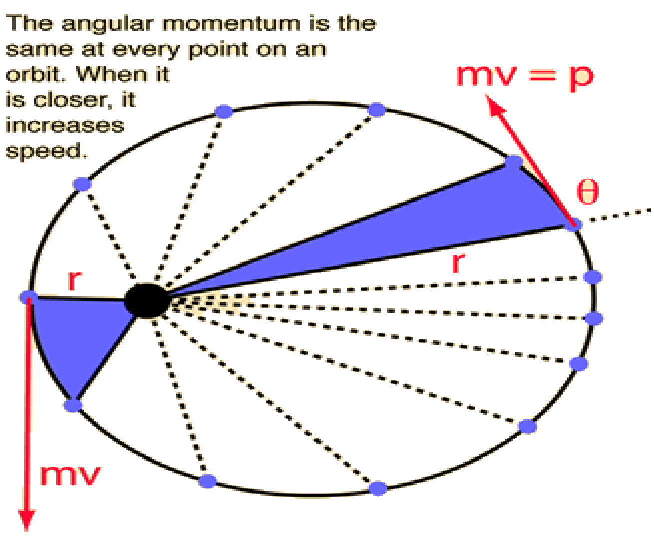
Videos







Angular momentum



The angular momentum of a particle of mass m with respect to a chosen origin is given by

L = mvr sin θ

or more formally by the vector product

L = r x p

The direction is given by the right hand rule which would give L the direction out of the diagram. For an orbit, angular momentum is conserved, and this leads to one of Kepler's laws. For a circular orbit, L becomes

L = mvr

Video

Reference pages

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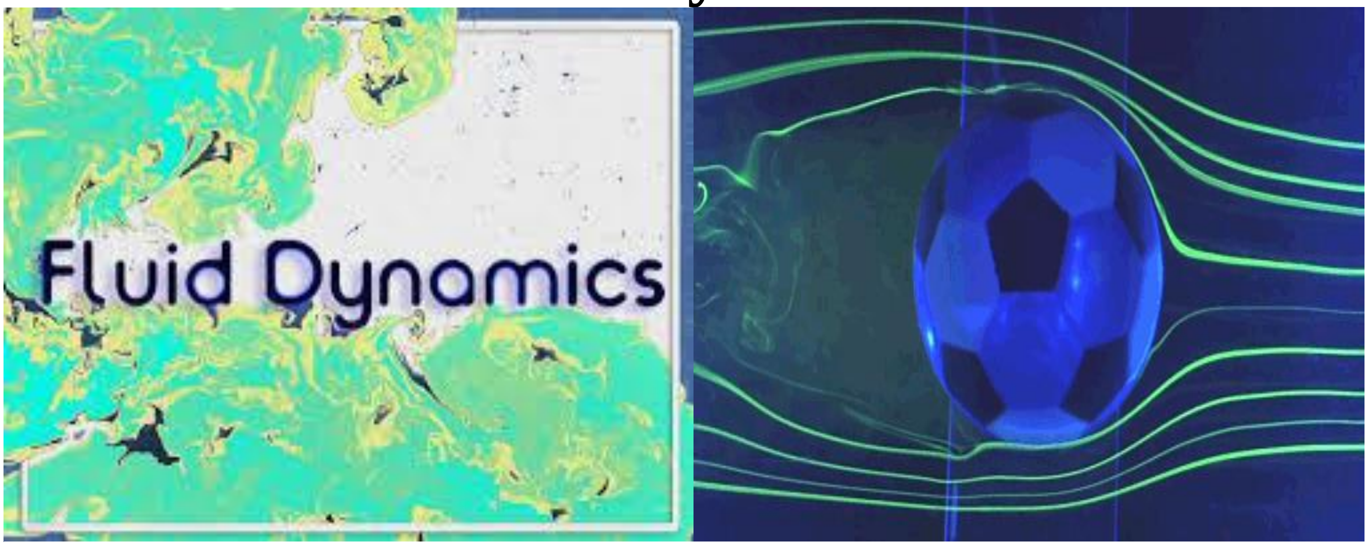
Unit – 6

Fluid dynamics



Topics	Understandings	Skills
• Streamline and Turbulent flow • Equation of continuity • Bernoulli's equation • Applications of Bernoulli's equation • Viscous fluids • Fluid Friction Terminal velocity	The students will: • define the terms: steady (streamline or laminar) flow, incompressible flow and non • viscous flow as applied to the motion of an ideal fluid. • explain that at a sufficiently high velocity, the flow of viscous fluid undergoes a • transition from laminar to turbulence conditions. • describe that the majority of practical examples of fluid flow and resistance to • motion in fluids involve turbulent rather than laminar conditions. • describe equation of continuity Av = Constant, for the flow of an ideal and • incompressible fluid and solve problems using it. • identify that the equation of continuity is a form of the principle of conservation of • mass. • describe that the pressure difference can arise from different rates of flow of a fluid	The students will: • investigate the effect of moving air on pressure by demonstrating with Venturi meter. • investigate the fall of spherical steel balls through a viscous medium and determine terminal velocity • coefficient of viscosity of the fluid • investigate the viscosity of different liquids by measuring the terminal velocity. • describe of systolic pressure and diastolic pressure and use sphygmomanometer to • measure blood pressure.

	• (Bernoulli effect). • derive Bernoulli equation in the form P + ½ ρv2 • + ρgh = constant • for the case of horizontal tube of flow. • interpret and apply Bernoulli Effect in the: filter pump, Venturi meter, in, atomizers, flow of air over an aero foil and in blood physics. • describe that real fluids are viscous fluids. • describe that viscous forces in a fluid cause a retarding force on an object moving through it.	

Chapter Overview

1.Streamline and Turbulent Flow

streamline flow. n. (General Physics) flow of a fluid in which its velocity at any point is constant or varies in a regular manner. It can be represented by streamlines. Also called: viscous flow Compare turbulent flow See also laminar flow.

(General Physics) flow of a fluid in which its velocity at any point is constant or varies in a regular manner. It can be represented by streamlines.

Streamline Flow

Streamline flow in fluids is defined as the flow in which the fluids flow in parallel layers such that there is no disruption or intermixing of the layers and at a given point, the velocity of each fluid particle passing by remains constant with time. Here, at low fluid velocities, there are no turbulent velocity fluctuations and the fluid tends to flow without lateral mixing. Here, the motion of particles of the fluid follows a particular order with respect to the particles moving in a straight line parallel to the wall of the pipe such that the adjacent layers slide past each other like playing cards.
To understand the liquid flow pattern better, click on the links provided below:

Reynolds Number

Poiseuille's Law Formula

Streamlines

Streamlines are defined as the path taken by particles of a fluid under steady flow conditions. If we represent the flow lines as curves, then the tangent at any point on the curve gives the direction of fluid velocity at that point.

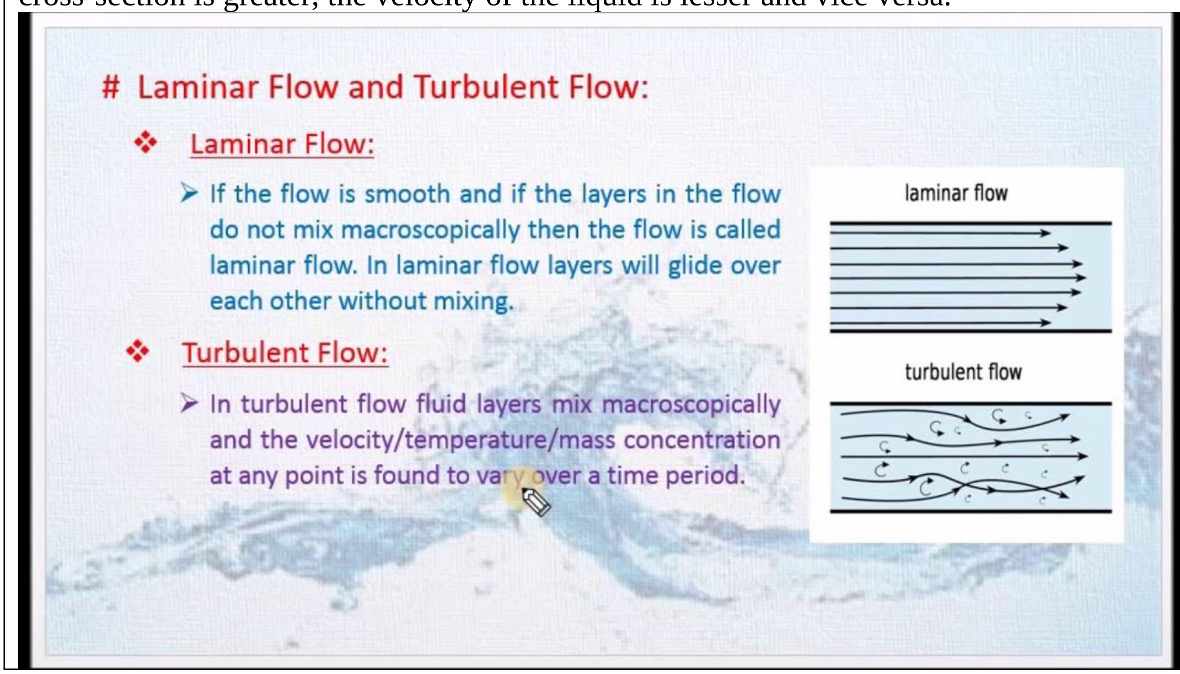
(a) Laminar flow

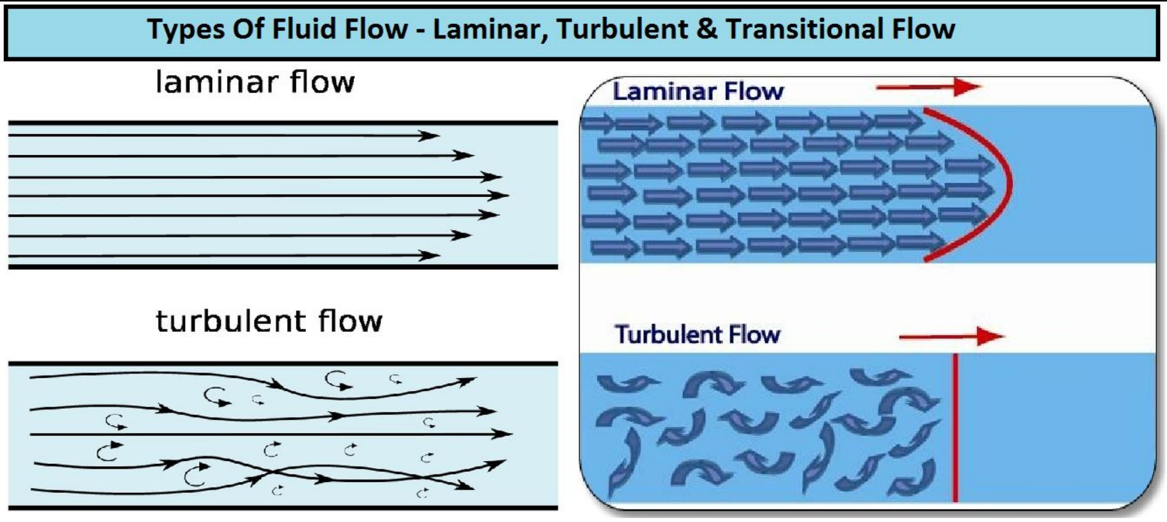
(b) Turbulent flow

Streamlines

As can be seen in the image above, the curves describe how the fluid particles move with respect to time. The curve provides a map for the flow of this given fluid, and for a steady flow. This map is stationary with time i.e., every particle passing a point behaves exactly as the previous particle that has just passed that point.

The streamlines in a laminar flow follow the equation of continuity, i.e., Av = constant, where, A is the cross-sectional area of the fluid flow and v is the velocity of the fluid at that point. Av is the defined as the volume flux or the flow rate of the fluid, which remains constant for steady flow. When the area of the cross-section is greater, the velocity of the liquid is lesser and vice versa.

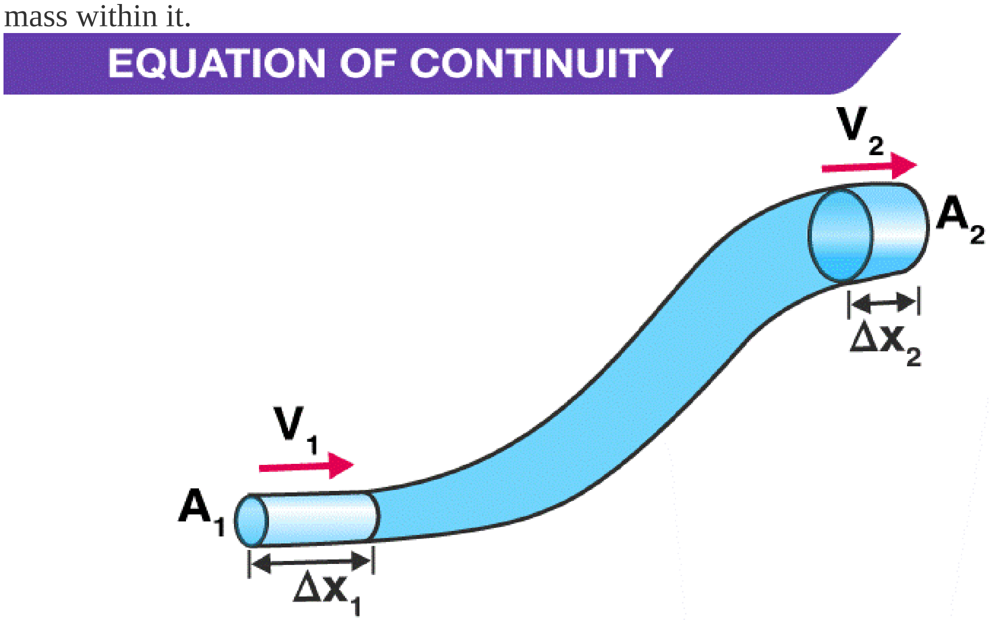




Video:

2.Equation of continuity:

The continuity equation reflects the fact that mass is conserved in any non-nuclear continuum mechanics analysis. The equation is developed by adding up the rate at which mass is flowing in and out of a control volume, and setting the net in-flow equal to the rate of change of mass within it.



Now, consider the fluid flows for a short interval of time in the tube. So, assume that short interval of time as Δt. In this time, the fluid will cover a distance of $\Delta x1$ with a velocity v1 at the lower end of the pipe.

At this time, the distance covered by the fluid will be:

$$\Delta x1 = v1\Delta t$$

Now, at the lower end of the pipe, the volume of the fluid that will flow into the pipe will be:

$$V = A1\ \Delta x1 = A1\ v1\ \Delta t$$

It is known that mass (m) = Density (ρ) × Volume (V). So, the mass of the fluid in $\Delta x1$ region will be:

$$\Delta m1 = \text{Density} \times \text{Volume}$$

=> $$\Delta m1 = \rho 1 A1 v1 \Delta t \text{ ———(Equation 1)}$$

Now, the mass flux has to be calculated at the lower end. Mass flux is simply defined as the mass of the fluid per unit time passing through any cross-sectional area. For the lower end with cross-sectional area A1, mass flux will be:

$$\Delta m1/\Delta t = \rho 1 A1 v1 \text{ ———(Equation 2)}$$

Similarly, the mass flux at the upper end will be:

$$\Delta m2/\Delta t = \rho 2 A2 v2 \text{ ———(Equation 3)}$$

Here, v2 is the velocity of the fluid through the upper end of the pipe i.e. through $\Delta x2$, in Δt time and A2, is the cross-sectional area of the upper end.

In this, the density of the fluid between the lower end of the pipe and the upper end of the pipe remains the same with time as the flow is steady. So, the mass flux at the lower end of the pipe is equal to the mass flux at the upper end of the pipe i.e. Equation 2 = Equation 3.

Thus,

$$\rho 1 A1 v1 = \rho 2 A2 v2 \text{ ———(Equation 4)}$$

This can be written in a more general form as:

ρ A v = constant

The equation proves the law of conservation of mass in fluid dynamics. Also, if the fluid is incompressible, the density will remain constant for steady flow. So, $\rho 1 = \rho 2$.

Thus, Equation 4 can be now written as:

$$A1\ v1 = A2\ v2$$

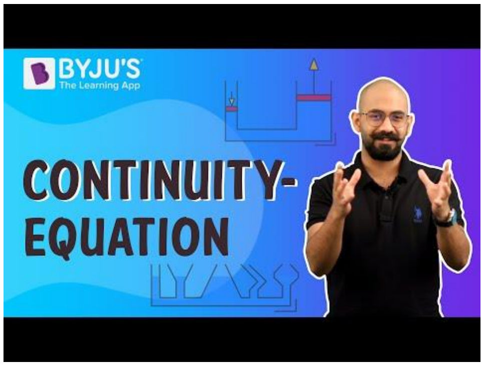
This equation can be written in general form as:

$$A\ v = \text{constant}$$

Now, if R is the volume flow rate, the above equation can be expressed as:

$$R = A\,v = \text{constant}$$

Video:



3.Bernoullie’s equation:

The simplified form of Bernoulli's equation can be summarized in the following memorable word equation: static pressure + dynamic pressure = total pressure. Every point in a steadily flowing fluid, regardless of the fluid speed at that point, has its own unique static pressure p and dynamic pressure q.

he Bernoulli equation states that

$$p + \frac{1}{2}\rho V^2 + \rho g h = constant$$

where p is the pressure, ρ is the density, V is the velocity, h is elevation, and g is the gravitational acceleration

Where

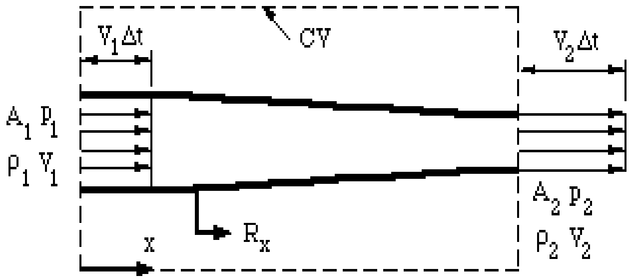
points 1 and 2 lie on a streamline,
the fluid has constant density,
the flow is steady, and
there is no friction.

Although these restrictions sound severe, the Bernoulli equation is very useful, partly because it is very simple to use and partly because it can give great insight into the balance between pressure, velocity and elevation.

How useful is Bernoulli's equation? How restrictive are the assumptions governing its use? Here we give some examples.

Pressure/velocity variation

Consider the steady, flow of a constant density fluid in a converging duct, without losses due to friction (figure 14). The flow therefore satisfies all the restrictions governing the use of Bernoulli's equation. Upstream and downstream of the contraction we make the one-dimensional assumption that the velocity is constant over the inlet and outlet areas and parallel.



One-dimensional duct showing control volume

When streamlines are parallel the pressure is constant across them, except for hydrostatic head differences (if the pressure was higher in the middle of the duct, for example, we would expect the streamlines to diverge, and vice versa). If we ignore gravity, then the pressures over the inlet and outlet areas are constant. Along a streamline on the centerline, the Bernoulli equation and the one-dimensional continuity equation give, respectively,

$$p_1 - p_2 = \frac{1}{2}\rho(V_2^2 - V_1^2)$$

and $$A_1V_1 = A_2V_2$$

Therefore,

$$A_2 < A_1, \quad V_2 > V_1$$

$$V_2 > V_1, \quad p_2 < p_1$$

decreasing area = increasing velocity
increasing velocity = decreasing pressure

These two observations provide an intuitive guide for analyzing fluid flows, even when the flow is not one-dimensional. For example, when fluid passes over a solid body, the streamlines get closer together, the flow velocity increases, and the pressure decreases. Airfoils are designed so that the flow over the top surface is faster than over the bottom surface, and therefore the average pressure over the top surface is less than the average pressure over the bottom surface, and a resultant force due to this pressure difference is produced. This is the source of lift on an airfoil. Lift is defined as the force acting on an airfoil due to its motion, in a direction normal to the direction of motion. Likewise, drag on an airfoil is defined as the force acting on an airfoil due to its motion, along the direction of motion.

An easy demonstration of the lift produced by an airstream requires a piece of notebook paper and two books of about equal thickness. Place the books four to five inches apart, and cover the gap with the paper. When you blow through the passage made by the books and the paper, what do you see? Why?

Two more examples:

Example 1

A table tennis ball placed in a vertical air jet becomes suspended in the jet, and it is very stable to small perturbations in any direction. Push the ball down, and it springs back to its equilibrium position; push it sideways, and it rapidly returns to its original position in the center of the jet. In the vertical direction, the weight of the ball is balanced by a force due to pressure differences: the pressure over the rear half of the sphere is lower than over the front half because of losses that occur in the wake (large eddies form in the wake that dissipate a lot of flow energy). To understand the balance of forces in the horizontal direction, you need to know that the jet has its maximum velocity in the center, and the velocity of the jet decreases towards its edges. The ball position is stable because if the ball moves sideways, its outer side moves into a region of lower velocity and higher pressure, whereas its inner side moves closer to the center where the velocity is higher and the pressure is lower. The differences in pressure tend to move the ball back towards the center.

Example 2

Suppose a ball is spinning clockwise as it travels through the air from left to right The forces acting on the spinning ball would be the same if it was placed in a stream of air moving from right to left, as shown in figure 15.

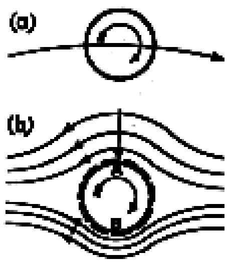
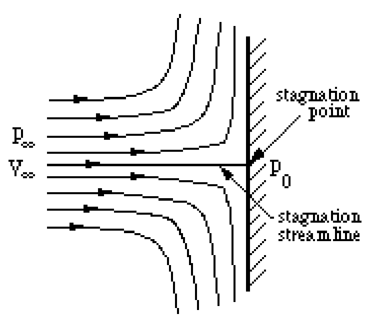


Figure 15. Spinning ball in an airflow

A thin layer of air (a boundary layer) is forced to spin with the ball because of viscous friction. At A the motion due to spin is opposite to that of the air stream, and therefore near A there is a region of low velocity where the pressure is close to atmospheric. At B, the direction of motion of the boundary layer is the same as that of the external air stream, and since the velocities add, the pressure in this region is below atmospheric. The ball experiences a force acting from A to B, causing its path to curve. If the spin was counterclockwise, the path would have the opposite curvature. The appearance of a side force on a spinning sphere or cylinder is called the Magnus effect, and it well known to all participants in ball sports, especially baseball, cricket and tennis players.

Stagnation pressure and dynamic pressure

Bernoulli's equation leads to some interesting conclusions regarding the variation of pressure along a streamline. Consider a steady flow impinging on a perpendicular plate (figure 16).



Stagnation point flow.

There is one streamline that divides the flow in half: above this streamline all the flow goes over the plate, and below this streamline all the flow goes under the plate. Along this dividing streamline, the fluid moves towards the plate. Since the flow cannot pass through the plate, the fluid must come to rest at the point where it meets the plate. In other words, it ``stagnates." The fluid along the dividing, or ``stagnation streamline" slows down and eventually comes to rest without deflection at the stagnation point.

Bernoulli's equation along the stagnation streamline gives

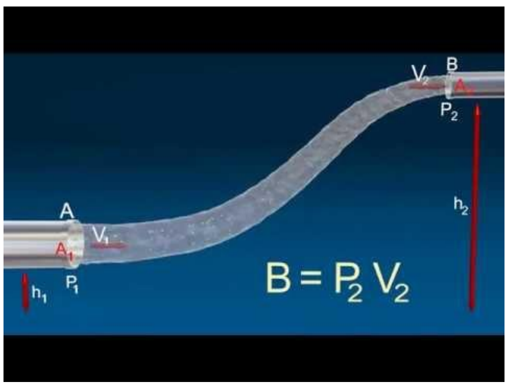
$$p_e + \frac{1}{2}\rho V_e^2 = p_0 + \frac{1}{2}\rho V_0^2$$

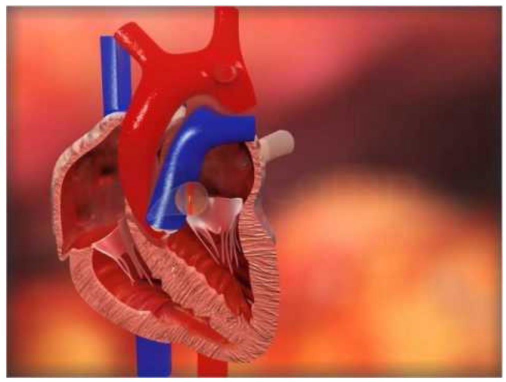
where the point e is far upstream and point 0 is at the stagnation point. Since the velocity at the stagnation point is zero,

$$\underset{\text{static pressure}}{p_e} + \underset{\text{dynamic pressure}}{\frac{1}{2}\rho V_e^2} = \underset{\text{stagnation pressure}}{p_0}$$

The stagnation or total pressure, p_0, is the pressure measured at the point where the fluid comes to rest. It is the highest pressure found anywhere in the flowfield, and it occurs at the stagnation point. It is the sum of the static pressure (p_0), and the dynamic pressure measured far upstream. It is called the dynamic pressure because it arises from the motion of the fluid.

Videos





4.Applications of Bernoulli’s equation:

All preceding applications of Bernoulli's equation involved simplifying conditions, such as constant height or constant pressure. The next example is a more general application of Bernoulli's equation in which pressure, velocity, and height all change

To find Pressure

In certain problems in fluid flows we know the velocities at two points of the streamline and pressure at one point. The unknown is the pressure of the fluid at the other point. In such cases (if they satisfy the required condition for Bernoulli’s Equation) we can use Bernoulli’s Equation to find the unknown pressure. One such example is

Flow through a Nozzle:

It’s a converging nozzle. Flow enters the nozzle at low speed, accelerates and leaves the nozzle at atmospheric pressure. We have to find the pressure at inlet. We can simply apply Bernoulli’s Equation between inlet and outlet points and calculate the unknown pressure assuming that the change in elevation in zero.
In this example there is no change in elevation. The converging nozzle causes fluid to accelerate. From the energy balance feature of the equation we can say the increase in velocity results in the drop in the pressure at the outlet of the nozzle.

To find Velocity

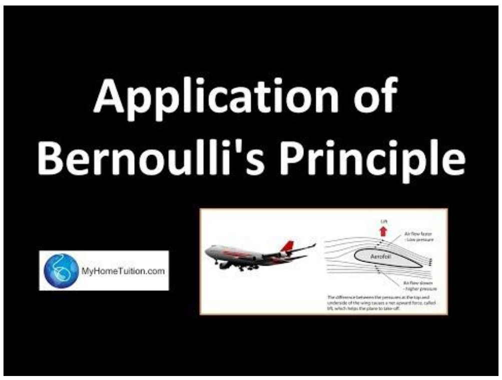
In problems where the pressure and elevation at two points and velocity at one point is known, and we have to find the unknown velocity, Bernoulli's Equation is applied to calculate the required velocity. One such example is

Flow through a Siphon:

Siphon is used to drain a fluid from a reservoir at a higher level to a lower level. Here it is required to find the velocity with which the fluid leaves the siphon. We apply Bernoulli's Equation between the reservoir surface and the exit point of the siphon where the fluid leaves the tube. Pressure at both points is same (atmospheric), velocity at the reservoir is negligible because the reservoir is large. Velocity at the exit point can be calculated by using the values of elevation at the two points.

In this example we can say the decrease in elevation or the potential head manifests as the velocity of the fluid at the exit point of the siphon tube.

Videos



5.Viscous fluids:

Viscosity is the property of a fluid which offers resistance to the movement of fluid. All the real fluids have a certain amount of viscosity, while a viscous fluid has a large amount of viscosity. Examples include-Honey, molasses, glues, Ketchup.

Viscosity is a phenomenon in which fluids resists their shear deformation by providing resistance between the layers of the fluid . Streamlined flow is generally the case in viscous fluids because the resistance offered reduces it's speed .

For example ,

If we consider the case of water and honey flowing in a tube ,we can observe that honey travels slower than that of water because it offers higher resistance to the shear deformation.

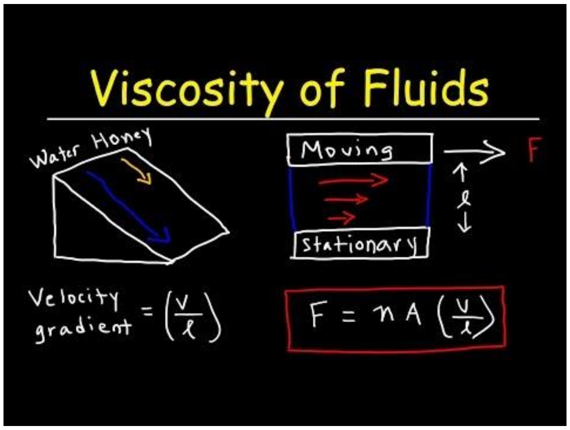
In the previous chapter on fluids, we introduced the basic ideas of pressure, fluid flow, the application of conservation of mass and of energy in the form of the continuity equation and of Bernoulli's equation, respectively, as well as hydrostatics. Throughout those discussions we restricted ourselves to ideal fluids, those that do not exhibit any frictional properties.

Often these can be neglected and the results of the previous chapter applied without any modifications whatsoever. Clearly mass is conserved even in the presence of viscous frictional forces and so the continuity equation is a very general result.

Real fluids, however, do not conserve mechanical energy, but over time will lose some of this well-ordered energy to heat through frictional losses. In this chapter we consider such behavior, known as viscosity, first in the case of simple fluids such as water. We study the effects of viscosity on the motion of simple fluids and on the

motion of suspended bodies, such as macromolecules, in these fluids, with special attention to flow in a cylinder, the most important geometry of flow in biology. The complex nature of blood as a fluid is studied next leading into a description and
physics perspective of the human circulatory system. We conclude the chapter with a discussion of surface tension and capillarity, two important surface phenomena in fluids. In Chapter 13 we return to the general notion of the loss of well-ordered
energy to heat in the context of thermodynamics.

Video:



6.Fluid Friction:

Fluid friction is the force that resists motion either within the fluid itself or of another medium moving through the fluid. There is internal friction, which is a result of the interactions between molecules of the fluid, and there is external friction, which refers to how a fluid interacts with other matter.

What Is a fluid?

Have you ever wondered why it's easier to squeeze a tube of toothpaste than it is to squeeze honey into your tea? Have you ever put your hand out the window while driving and felt the wind resistance pushing back on your hand? Both relate to fluid friction.

Let's first get a grasp on fluids. A fluid, in contrast to a solid, is a material with no fixed shape that constantly deforms when acted upon by an outside force. You probably think of things like water and coffee as fluids; however, gases, such as air, and substances like motor oil are also fluids. The property that causes them to seem very different from each other is viscosity. Viscosity is the measure of a fluid's resistance to flow because of its internal friction. This is why honey is much harder to squeeze out of the bottle than ketchup. It also describes why it is more difficult to move in a swimming pool than it is on dry land.

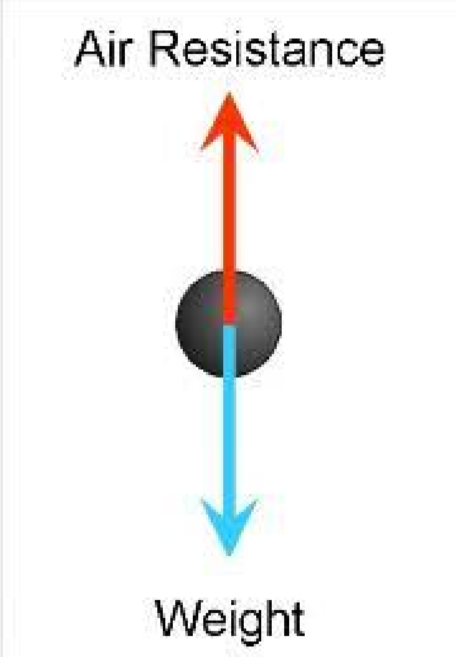
What Is Fluid Friction?

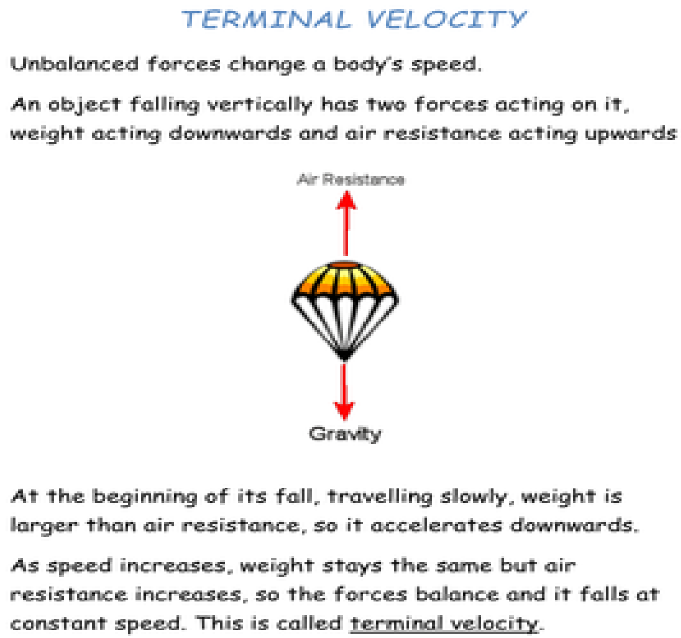
Fluid friction is the force that resists motion either within the fluid itself or of another medium moving through the fluid. There is internal friction, which is a result of the interactions between molecules of the fluid, and there is external friction, which refers to how a fluid interacts with other matter.

Internal Friction

Let's first take a look at internal fluid friction. To the naked eye, a fluid is a continuous medium. If you look at a fluid under a high powered microscope, however, you'd see that fluids are actually made up of molecules separated by a considerable amount of empty space. To deform a fluid (e.g., squeeze honey through a small hole), the molecules need to move relative to each other by squeezing past or displacing one another. This is internal friction and is what prevents a fluid from flowing. The more internal friction, the harder it is to get the molecules to move and the harder it is to force the fluid to deform. But internal friction isn't always a negative consequence. For instance, without internal friction, you would not be able to drink through a straw because the fluid would not be cohesive enough to enable it to be transported in such a manner.

7.Terminal velocity:





Is the maximum velocity attainable by an object as it falls through a fluid (air is the most common example). It occurs when the sum of the drag force (Fd) and the buoyancy is equal to the downward force of gravity (FG) acting on the object. Since the net force on the object is zero, the object has zero acceleration.
In fluid dynamics, an object is moving at its terminal velocity if its speed is constant due to the restraining force exerted by the fluid through which it is moving .

As the speed of an object increases, so does the drag force acting on it, which also depends on the substance it is passing through (for example air or water). At some speed, the drag or force of resistance will equal the gravitational pull on the object (buoyancy is considered below). At this point the object ceases to accelerate and continues falling at a constant speed called the terminal velocity (also called settling velocity). An object moving downward faster than the terminal velocity (for example because it was thrown downwards, it fell from a thinner part of the atmosphere, or it changed shape) will slow down until it reaches the terminal velocity. Drag depends on the projected area, here, the object's cross-section or silhouette in a horizontal plane. An object with a large projected area relative to its mass, such as a parachute, has a lower terminal velocity than one with a small projected area relative to its mass, such as a bullet. In general, for the same shape and material, the terminal velocity of an object increases with size. This is because the downward force (weight) is proportional to the cube of the linear dimension, but the air resistance is approximately proportional to the cross-section area which increases only as the square of the linear dimension. For very small objects such as dust and mist, the terminal velocity is easily overcome by convection currents which prevent them from reaching the ground and hence they stay suspended in the air for indefinite periods. Air pollution and fog are examples of this.

Learning Objectives

Define the terms: steady (streamline or laminar) flow, incompressible flow and non viscous flow as applied to the motion of an ideal fluid.

Explain that at a sufficiently high velocity, the flow of viscous fluid undergoes a transition from laminar to turbulence conditions.
Describe that the majority of practical examples of fluid flow and resistance tomotion in fluids involve turbulent rather than laminar conditions.
Describe equation of continuity Aν = Constant, for the flow of an ideal and incompressible fluid and solve problems using it.
Identify that the equation of continuity is a form of the principle of conservation of mass.
Describe that the pressure difference can arise from different rates of flow of a fluid (Bernoulli effect).
Derive Bernoullie equation in the form P + ½ ρv2 + ρgh = constant for the case of horizontal tube of flow.
Interpret and apply Bernoulli Effect in the: filter pump, Venturi meter, in, atomizers, flow of air over an aerofoil and in blood physics.
Describe that real fluids are viscous fluids.
Describe that viscous forces in a fluid cause a retarding force on an object moving through it.

Conceptual linkage:

[2]This chapter is built on
Work & Energy Physics IX
Dynamics Physics IX
Properties of Matter Physics IX

Explain how the magnitude of the viscous force in fluid flow depends on the shape and velocity of the object.
Apply dimensional analysis to confirm the form of the equation F = Aηrv where 'A' is a dimensionless constant (Stokes' Law) for the drag force under laminar conditions in a viscous fluid.
Apply Stokes' law to derive an expression for terminal velocity of spherical body falling through a viscous fluid.

Length

120-150 minutes depending on age group/prior knowledge

Reference pages

https://www.thefreedictionary.com/streamline+flow
https://www.google.com/search?q=Streamline+and+Turbulent+flow&source=lmns&bih=625&biw=1349&rlz=1C1CAFB_enPK904PK905&hl=en&ved=2ahUKEwjdntWvqfTpAhUE4RoKHSkHAZgQ_AUoAHoECAEQAA
https://www.google.com/search?q=streamline+and+turbulent+flow&rlz=1C1CAFB_enPK904PK905&tbm=isch&source=iu&ictx=1&fir=gVY10hRSJpmHTM%253A%252CwIdYUg0jSErcvM%252C_&vet=1&usg=AI4_-kTbLJXTfnL0wuws-hfaI2ORNV9abQ&sa=X&ved=2ahUKEwiWncj7svbpAhUEsaQKHZCCB7UQ_h0wA3oECAsQCA&biw=1366&bih=625#imgrc=Mr4JkhOETcFkaM
https://www.google.com/search?bih=625&biw=1366&rlz=1C1CAFB_enPK904PK905&hl=en&ei=C2HgXuCZOMbQ6QSj44CQBQ&q=Equation+of+continuity%3A&oq=Equation+of+continuity%3A&gs_lcp=CgZwc3ktYWIQAzICCAAyAggAMgIIADICCAAyAggAMgIIADICCAAyAggAMgIIADICCABQ6hxY0TNgpz1oAXAAeACAAYkDiAGJA5IBAzMtMZgBAKABAaABAqoBB2d3cy13aXqwAQA&sclient=psy-ab&ved=0ahUKEwigy8CGtPbpAhVGaJoKHaMxAFIQ4dUDCAw&uact=5
https://www.google.com/search?q=Bernoullie%E2%80%99s+equation&rlz=1C1CAFB_enPK904PK905&oq=Bernoullie%E2%80%99s+equation&aqs=chrome..69i57j0l7.1658j0j8&sourceid=chrome&ie=UTF-8
https://www.brighthubengineering.com/hydraulics-civil-engineering/53072-applications-of-bernoullis-equation/

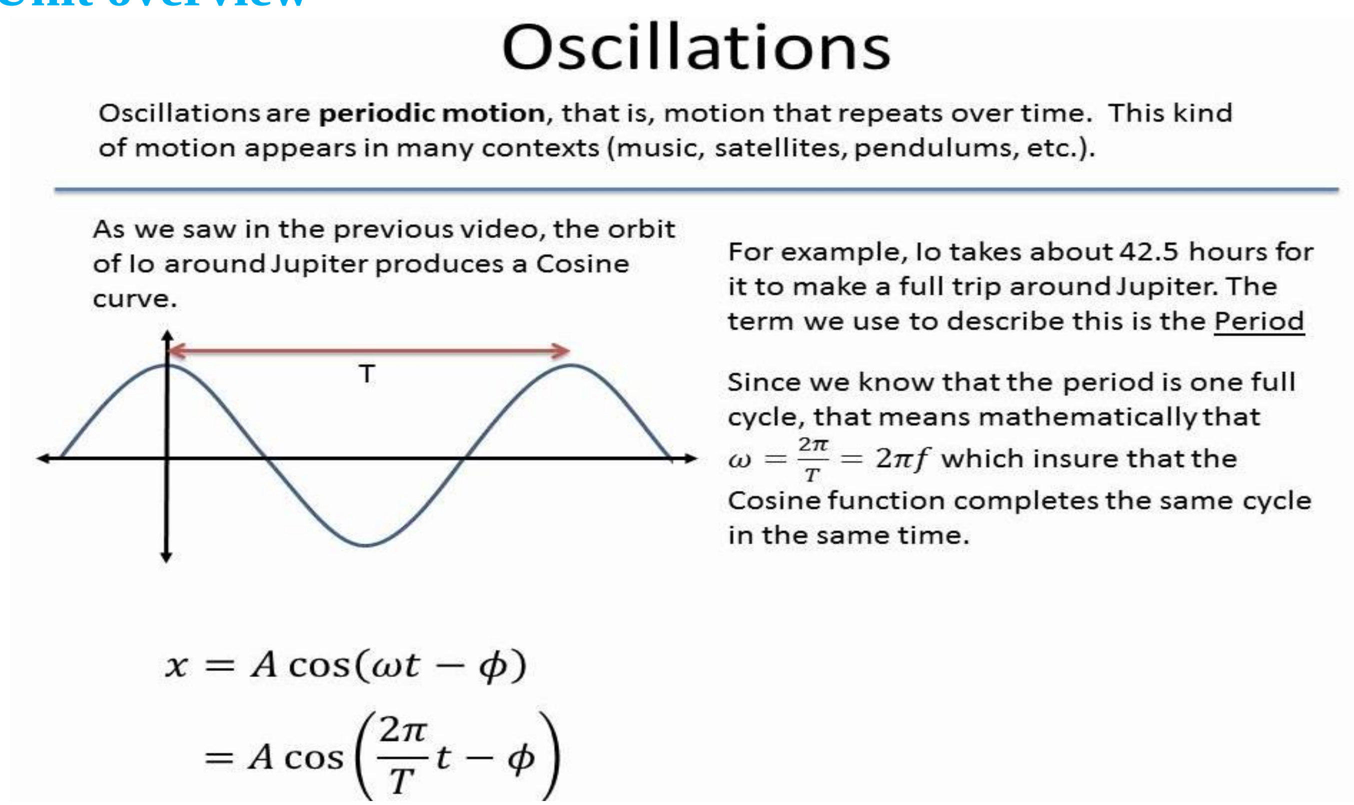
Unit 07

Oscillations

Topic	Understandings	Skills
• Simple Harmonic Motion (S.H.M) • Circular motion and SHM • Practical SHM system(mass spring and simple pendulum) • Energy conservation in SHM • Free and forced oscillations • Resonance • Damped oscillations	The students will: • Describe simple examples of free oscillations. • Describe necessary conditions for execution of simple harmonic motions. • Describe that when an object moves in a circle, the motion of its projection on the diameter of the circles is SHM. • Define the terms amplitude, period, frequency, angular frequency and phase difference and express the period in terms of both frequency and angular frequency. • Identify and use the equation; a= ω2x as the defining equation of SHM. • Prove that the motion of mass attached to a spring is SHM.	The students will: • Verify that the time period of the simple pendulum is directly proportional to the square root of its length and hence find the value of g from the graph. • Determine the acceleration due to gravity by oscillating mass-spring system. • Determine the value of g by vibrating a metal lamina suspending from different points.

	• Describe the interchanging between kinetic energy and potential energy during SHM. • Analyze the motion of a simple pendulum is SHM and calculate its time period. • Describe practical examples of free and forced oscillations (resonance). • Describe graphically how the amplitude of a forced oscillation changes with frequency near to the natural frequency of the system. • Describe practical examples of damped oscillations with particular reference to the efforts of the degree of damping and the importance of critical damping in cases such as a car suspension system. • Describe qualitatively the factors which determine the frequency response and sharpness of the resonance.	

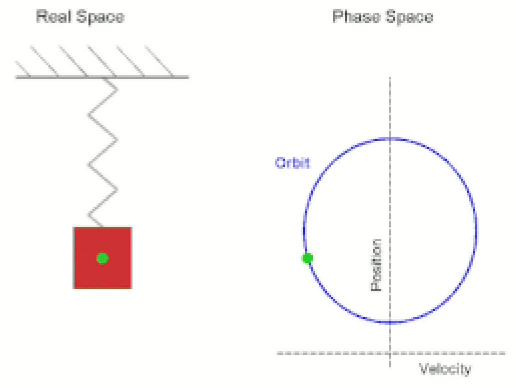
Unit overview



Simple Harmonic Motion (S.H.M)

Simple harmonic motion is defined as a periodic motion of a point along a straight line, such that its acceleration is always towards a fixed point in that line and is proportional to its distance from that point.

The motion of a particle moving along a straight line with an acceleration whose direction is always towards a fixed point on the line and whose magnitude is proportional to the distance from the fixed point is called simple harmonic motion [SHM].



Simple harmonic motion shown both in real space and phase space. The orbit is periodic. (Here the velocity and position axes have been reversed from the standard convention to align the two diagrams)

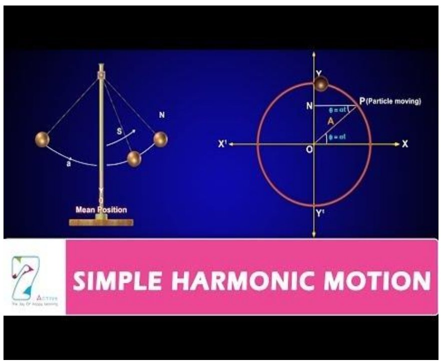
In the diagram, a simple harmonic oscillator, consisting of a weight attached to one end of a spring, is shown. The other end of the spring is connected to a rigid support such as a wall. If the system is left at rest at the equilibrium position then there is no net force acting on the mass. However, if the mass is displaced from the equilibrium position, the spring exerts a restoring elastic force that obeys Hooke's law.

Mathematically, the restoring force F is given by

$F = - kx$

where F is the restoring elastic force exerted by the spring (in SI units: N), k is the spring constant ($N \cdot m^{-1}$), and x is the displacement from the equilibrium position (m).

Videos

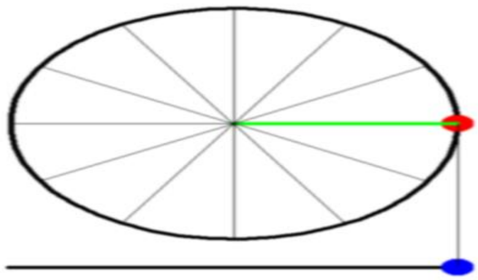


References

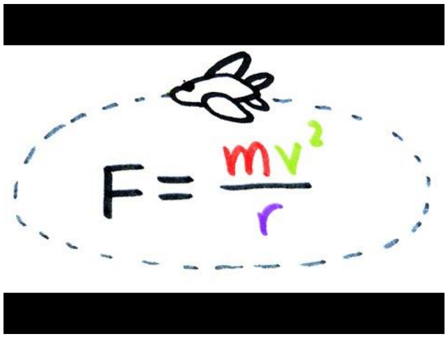
https://www.sciencedirect.com/topics/engineering/simple-harmonic-motion
https://en.wikipedia.org/wiki/Simple_harmonic_motion

Circular motion

Uniform Circular Motion describes the movement of an object traveling a circular path with constant speed. The one-dimensional projection of this motion can be described as simple harmonic motion. A point P moving on a circular path with a constant angular velocity ω is undergoing uniform circular motion.



video

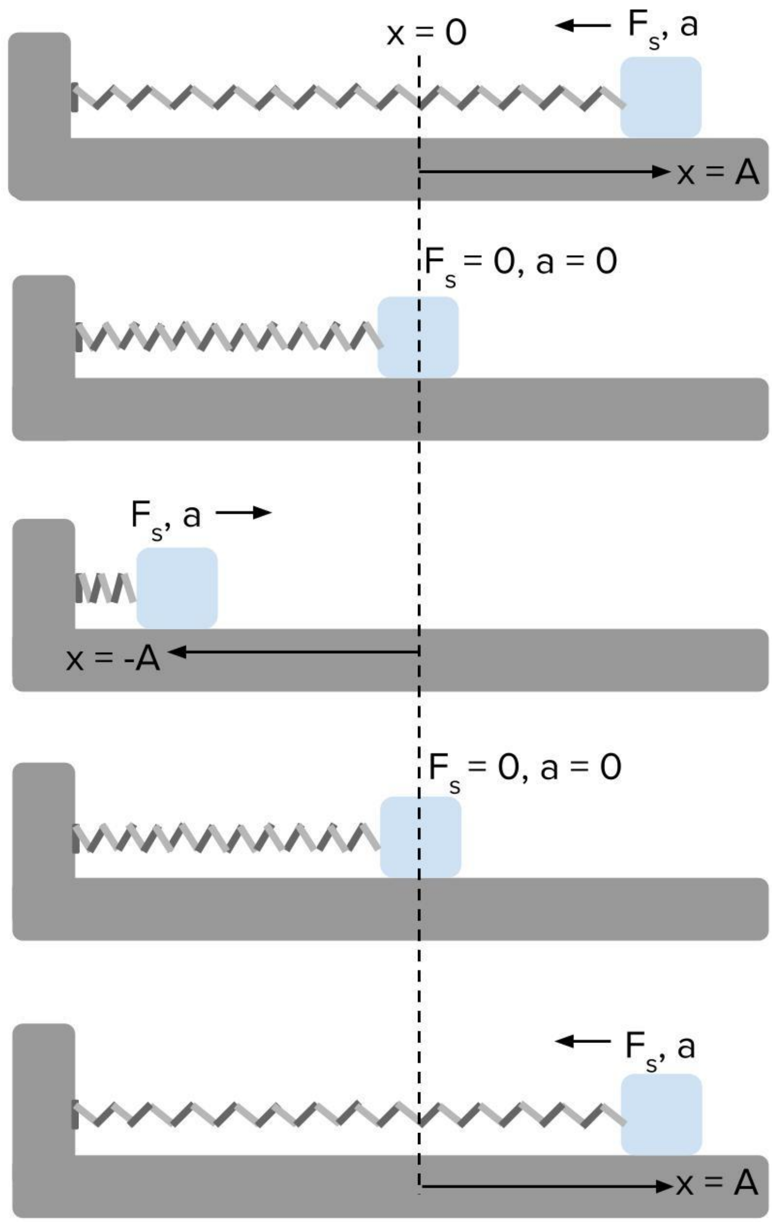


Practical S.H.M system(mass spring and simple pendulum)

Mass spring

Simple harmonic motion is governed by a restorative force. For a spring-mass system, such as a block attached to a spring, the spring force is responsible for the oscillation.

$F_s = -kx$



This image shows a spring-mass system oscillating through one cycle about a central equilibrium position. The vectors of force, acceleration, and displacement from equilibrium are given at each for the five positions shown.

Since the restoring force is proportional to displacement from equilibrium, both the magnitude of the restoring force and the acceleration is the greatest at the maximum points of displacement. The negative sign tells us that the force and acceleration are in the opposite direction from displacement.

$$F=ma$$

$$-kx=ma$$

$$a=-kx\backslash m$$

The mass's displacement, velocity, and acceleration over time can be visualized in the graphs below

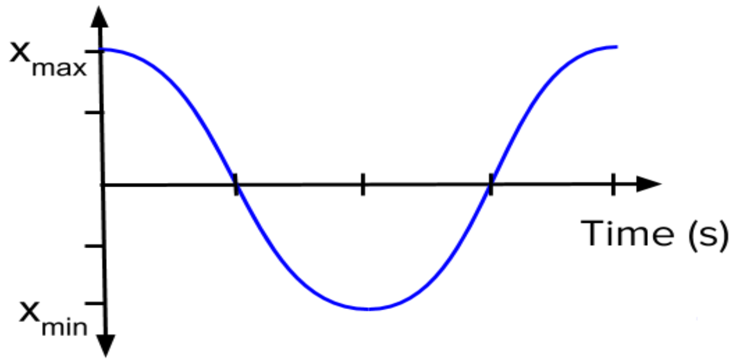


Figure 2. The position vs. time graph for the spring-mass system in Figure 1.

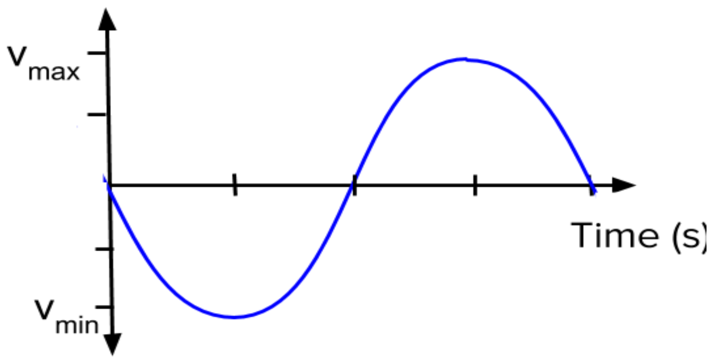


Figure 3. The velocity vs. time graph for the spring-mass system in Figure 1.

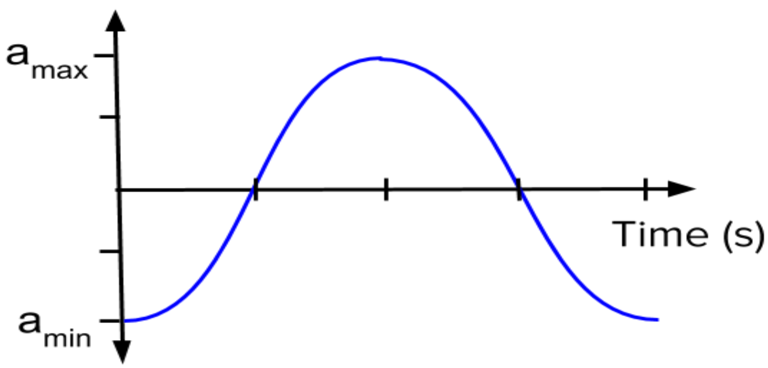
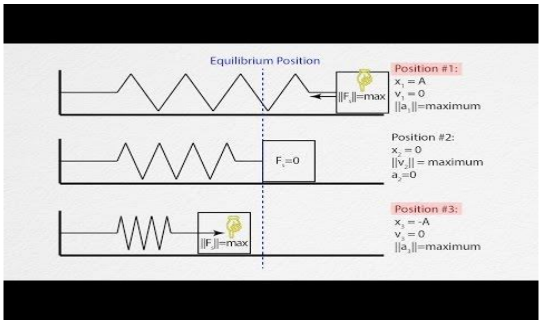


Figure 4. The acceleration vs. time graph for the spring-mass system in figure 1.

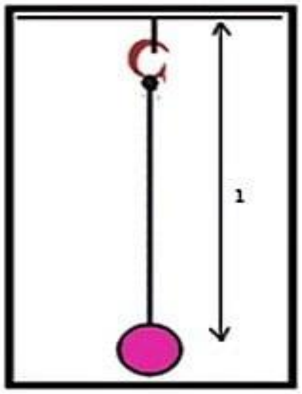
Videos

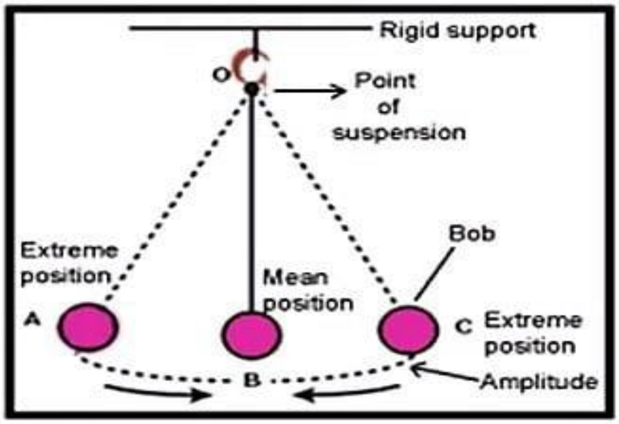


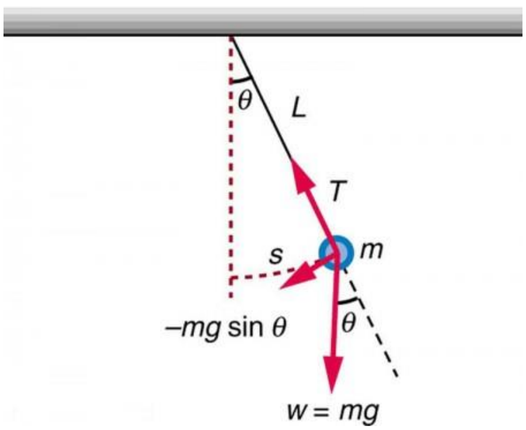
Reference

https://www.khanacademy.org/science/ap-physics-1/simple-harmonic-motion-ap/introduction-to-simple-harmonic-motion-ap/a/introduction-to-simple-harmonic-motion-review

Simple pendulum







We see that a simple pendulum has a small-diameter bob and a string that has a very small mass but is strong enough not to stretch appreciably. The linear displacement from equilibrium is *s*, the length of the arc. Also shown are the forces on the bob, which result in a net force of $-mg \sin\theta$ toward the equilibrium position—that is, a restoring force.

Pendulums are in common usage. Some have crucial uses, such as in clocks; some are for fun, such as a child's swing; and some are just there, such as the sinker on a fishing line. For small displacements, a pendulum is a simple harmonic oscillator. A *simple pendulum* is defined to have an object that has a small mass, also known as the pendulum bob, which is suspended from a light wire or string, such as shown in Figure 1. Exploring the simple pendulum a bit further, we can discover the conditions under which it performs simple harmonic motion, and we can derive an interesting expression for its period.

We begin by defining the displacement to be the arc length *s*. We see from Figure 1 that the net force on the bob is tangent to the arc and equals $-mg \sin\theta$. (The weight mg has components $mg \cos\theta$ along the string and $mg \sin\theta$ tangent to the arc.) Tension in the string exactly cancels the component $mg \cos\theta$ parallel to the string. This leaves a *net* restoring force back toward the equilibrium position at $\theta = 0$.

Now, if we can show that the restoring force is directly proportional to the displacement, then we have a simple harmonic oscillator. In trying to determine if we have a simple harmonic oscillator, we should note that for small angles (less than about 15º), $\sin\theta \approx \theta$ ($\sin\theta$ and θ differ by about 1% or less at smaller angles). Thus, for angles less than about 15º, the restoring force F is

$F \approx -mg\theta$.

The displacement *s* is directly proportional to θ. When θ is expressed in radians, the arc length in a circle is related to its radius (L in this instance) by $s = L\theta$, so that

$\theta = sL$

.
For small angles, then, the expression for the restoring force is:

$F \approx -\frac{mg}{L}s$

This expression is of the form: $F = -kx$, where the force constant is given by $k=\frac{mg}{L}$ and the displacement is given by $x = s$. For angles less than about 15º, the restoring force is directly proportional to the displacement, and the simple pendulum is a simple harmonic oscillator.

Using this equation, we can find the period of a pendulum for amplitudes less than about 15º. For the simple pendulum:

$T=2\pi\sqrt{\frac{m}{k}}=2\pi\sqrt{\frac{m}{mg/L}}$

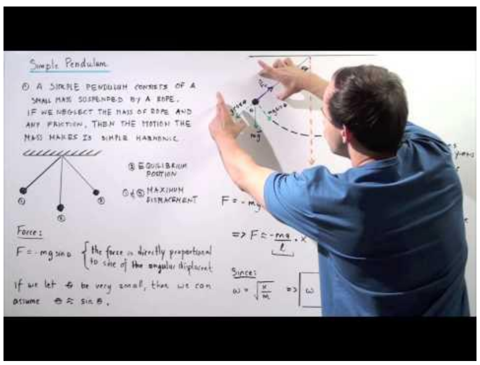
Thus,

$$T=2\pi\sqrt{\frac{L}{g}}$$

for the period of a simple pendulum. This result is interesting because of its simplicity. The only things that affect the period of a simple pendulum are its length and the acceleration due to gravity. The period is completely independent of other factors, such as mass. As with simple harmonic oscillators, the period T for a pendulum is nearly independent of amplitude, especially if θ is less than about 15º. Even simple pendulum clocks can be finely adjusted and accurate.

Note the dependence of T on g. If the length of a pendulum is precisely known, it can actually be used to measure the acceleration due to gravity.

Videos



Refrence

https://courses.lumenlearning.com/physics/chapter/16-4-the-simple-pendulum/

Energy conservation in SHM

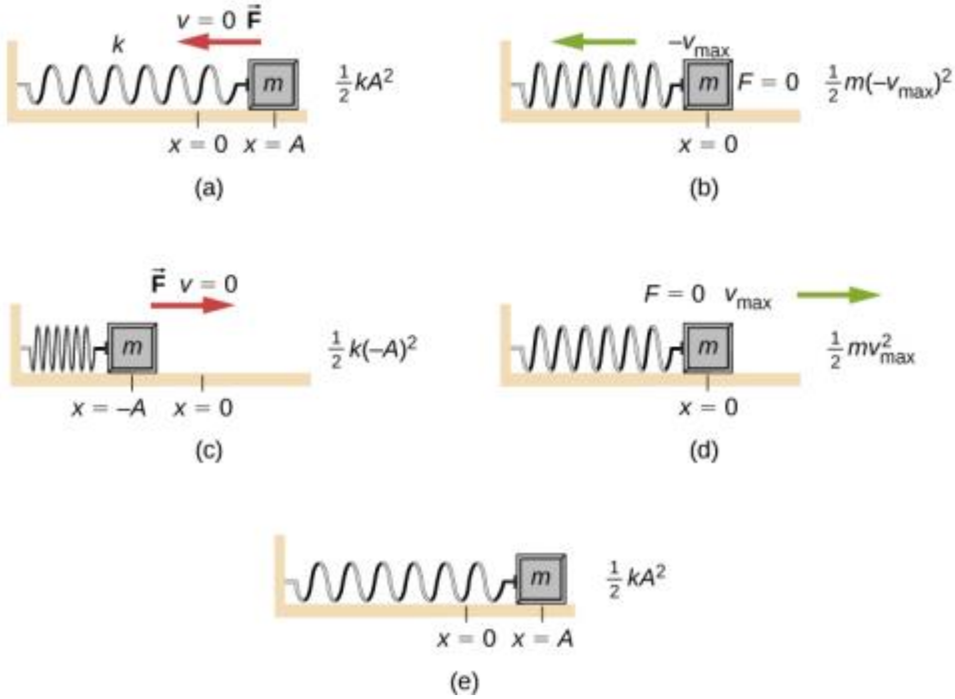
Energy and the Simple Harmonic Oscillator

To study the energy of a simple harmonic oscillator, we need to consider all the forms of energy. Consider the example of a block attached to a spring, placed on a frictionless surface, oscillating in SHM. The potential energy stored in the deformation of the spring is

$$U=1/2kx^2.$$

In a simple harmonic oscillator, the energy oscillates between kinetic energy of the mass $K = 1/2mv^2$ and potential energy $U = 1/2kx^2$ stored in the spring. In the SHM of the mass and spring system, there are no dissipative forces, so the total energy is the sum of the potential energy and kinetic energy. In this section, we consider the conservation of energy of the system. The concepts examined are valid for all simple harmonic oscillators, including those where the gravitational force plays a role.

, which shows an oscillating block attached to a spring. In the case of undamped SHM, the energy oscillates back and forth between kinetic and potential, going completely from one form of energy to the other as the system oscillates. So for the simple example of an object on a frictionless surface attached to a spring, the motion starts with all of the energy stored in the spring as elastic potential energy. As the object starts to move, the elastic potential energy is converted into kinetic energy, becoming entirely kinetic energy at the equilibrium position. The energy is then converted back into elastic potential energy by the spring as it is stretched or compressed. The velocity becomes zero when the kinetic energy is completely converted, and this cycle then repeats. Understanding the conservation of energy in these cycles will provide extra insight here and in later applications of SHM, such as alternating circuits.



The transformation of energy in SHM for an object attached to a spring on a frictionless surface. (a) When the mass is at the position x = + A, all the energy is stored as potential energy in the spring $U = 12kA^2$. The kinetic energy is equal to zero because the velocity of the mass is zero. (b) As the mass moves toward x = −A, the mass crosses the position x = 0. At this point, the spring is neither extended nor compressed, so the potential energy stored in the spring is zero. At x = 0, the total energy is all kinetic energy where $K = 12m(-v_{max})^2$. (c) The mass continues to move until it reaches x = −A where the mass stops and starts moving toward x = + A. At the position x = −A, the total energy is stored as potential energy in the compressed $U = 12k(-A)^2$ and the kinetic energy is zero. (d) As the mass passes through the position x = 0, the kinetic energy is $K = 12mv_{max}^2$ and the potential energy stored in the spring is zero. (e) The mass returns to the position x = + A, where K = 0 and
$U=1/2kA^2$.
, which shows the energy at specific points on the periodic motion. While staying constant, the energy oscillates between the kinetic energy of the block and the potential energy stored in the spring:

$$E_{Total}=U+K=1/2kx^2+1/2mv^2$$

The motion of the block on a spring in SHM is defined by the position $x(t) = A\cos\omega t + \phi)$ with a velocity of $v(t) = -A\omega\sin(\omega t + \phi)$. Using these equations, the trigonometric identity $\cos^2\theta + \sin^2\theta = 1$ and $\omega=\sqrt{k/m}$, we can find the total energy of the system:

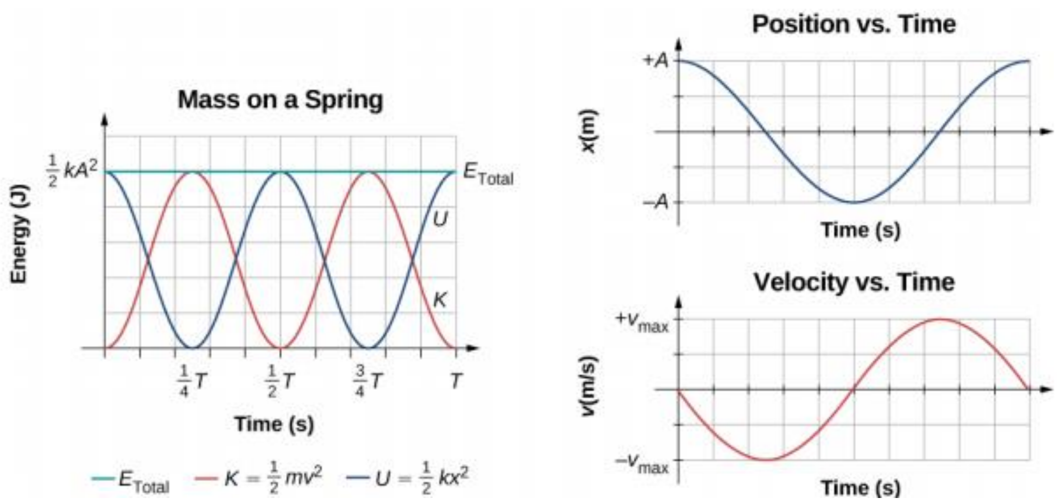
$$
\begin{aligned}
E_{Total} &= \frac{1}{2}kA^2\cos^2(\omega t+\phi)+\frac{1}{2}mA^2\omega^2\sin^2(\omega t+\phi)\\
&= \frac{1}{2}kA^2\cos^2(\omega t+\phi)+\frac{1}{2}mA^2\left(\frac{k}{m}\right)\sin^2(\omega t+\phi)\\
&= \frac{1}{2}kA^2\cos^2(\omega t+\phi)+\frac{1}{2}kA^2\sin^2(\omega t+\phi)\\
&= \frac{1}{2}kA^2\cos^2(\omega t+\phi)+\frac{1}{2}mA^2\omega^2\sin^2(\omega t+\phi)\\
&= \frac{1}{2}kA^2(\cos^2(\omega t+\phi)+\sin^2(\omega t+\phi))\\
&= \frac{1}{2}kA^2.
\end{aligned}
$$

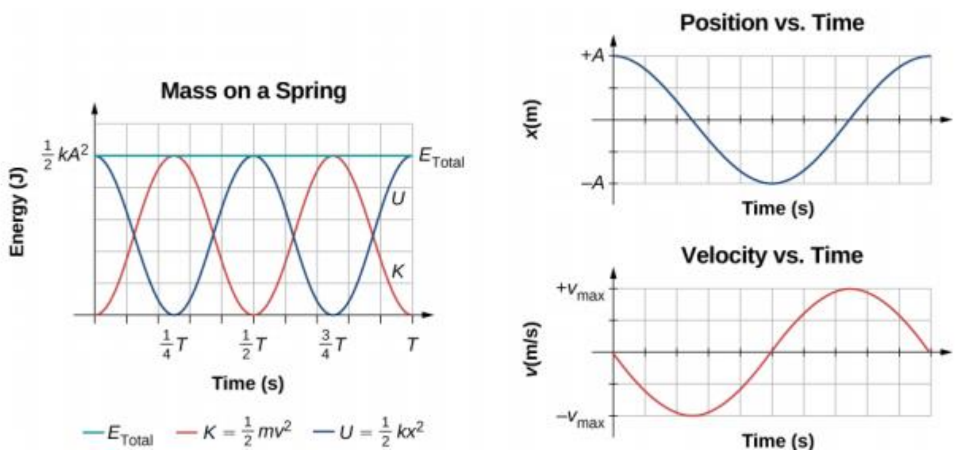
The total energy of the system of a block and a spring is equal to the sum of the potential energy stored in the spring plus the kinetic energy of the block and is proportional to the square of the amplitude $E_{Total} = 1/2kA^2$. The total energy of the system is constant.

A closer look at the energy of the system shows that the kinetic energy oscillates like a sine-squared function, while the potential energy oscillates like a cosine-squared function. However, the total energy for the system is constant and is proportional to the amplitude squared.

shows a plot of the potential, kinetic, and total energies of the block and spring system as a function of time. Also plotted are the position and velocity as a function of time. Before time t = 0.0 s, the block is attached to the spring and placed at the equilibrium position. Work is done on the block by applying an external force, pulling it out to a position of x = + A. The system now has potential energy stored in the spring. At time t = 0.00 s, the position of the block is equal to the amplitude, the potential energy stored in the spring is equal to U = 12

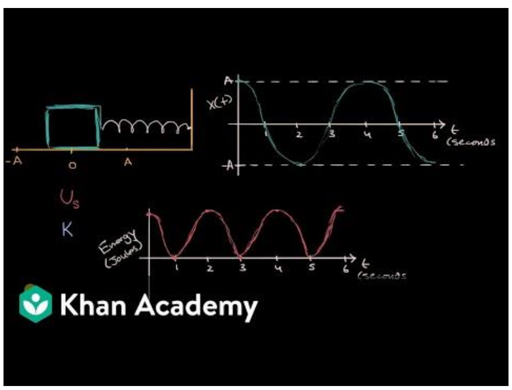
kA^2, and the force on the block is maximum and points in the negative x-direction ($F_S = -kA$). The velocity and kinetic energy of the block are zero at time t = 0.00 s. At time t = 0.00 s, the block is released from rest.

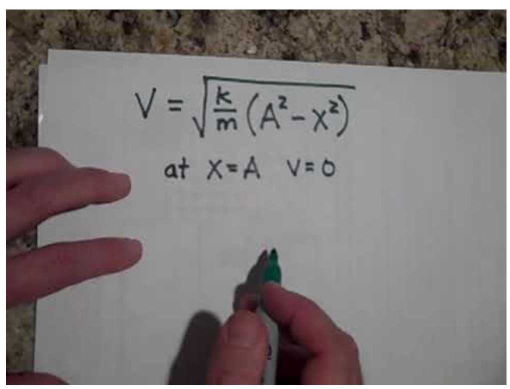




Graph of the kinetic energy, potential energy, and total energy of a block oscillating on a spring in SHM. Also shown are the graphs of position versus time and velocity versus time. The total energy remains constant, but the energy oscillates between kinetic energy and potential energy. When the kinetic energy is maximum, the potential energy is zero. This occurs when the velocity is maximum and the mass is at the equilibrium position. The potential energy is maximum when the speed is zero. The total energy is the sum of the kinetic energy plus the potential energy and it is constant.

Videos





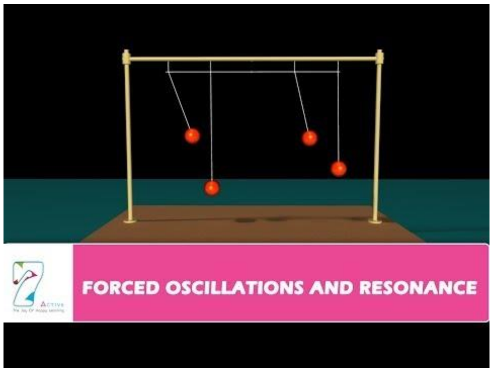
Reference

https://phys.libretexts.org/Bookshelves/University_Physics/Book%3A_University_Physics_(OpenStax)/Map%3A_University_Physics_I__Mechanics%2C_Sound%2C_Oscillations%2C_and_Waves_(OpenStax)/15%3A_Oscillations/15.03%3A_Energy_in_Simple_Harmonic_Motion

Free and forced oscillations

If an oscillator is displaced and then released it will begin to vibrate. If no more external forces are applied to the system it is a *free oscillator*. If a force is continually or repeatedly applied to keep the oscillation going, it is a *forced oscillator*

Videos



Reference

http://salfordacoustics.co.uk/sound-waves/oscillation/free-oscillations-forced-oscillations-and-resonance

Resonance

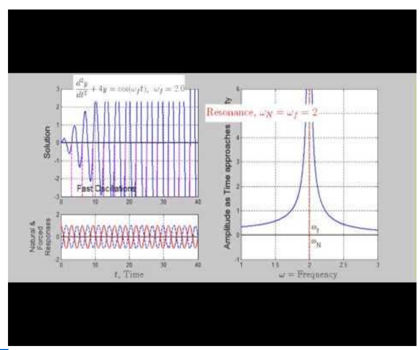
Resonance occurs when a material oscillates at a high amplitude at a specific frequency. We call this frequency resonant frequency. The dictionary defines resonance as,

"the state of a system in which an abnormally large vibration is produced in response to an external stimulus, occurring when the frequency of the stimulus is the same, or nearly the same, as the natural vibration frequency of the system."

Physics defines Resonance as

A phenomenon in which an external force or a vibrating system forces another system around it to vibrate with greater amplitude at a specified frequency of operation.

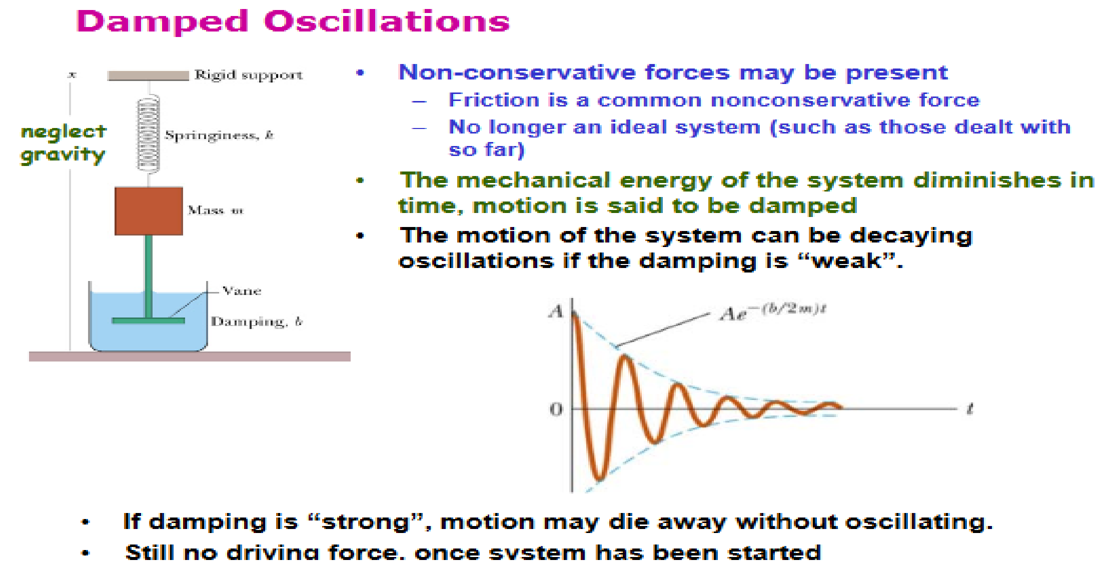
Videos



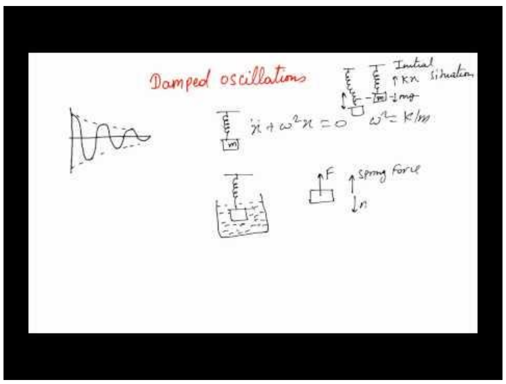
Reference

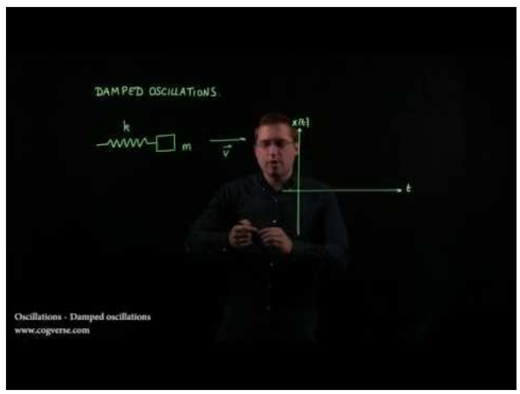
https://byjus.com/physics/resonance/

Damped Oscillations



Videos





Reference

https://web.njit.edu/~kenahn/11spring/phys106/Lecture/L23.pdf

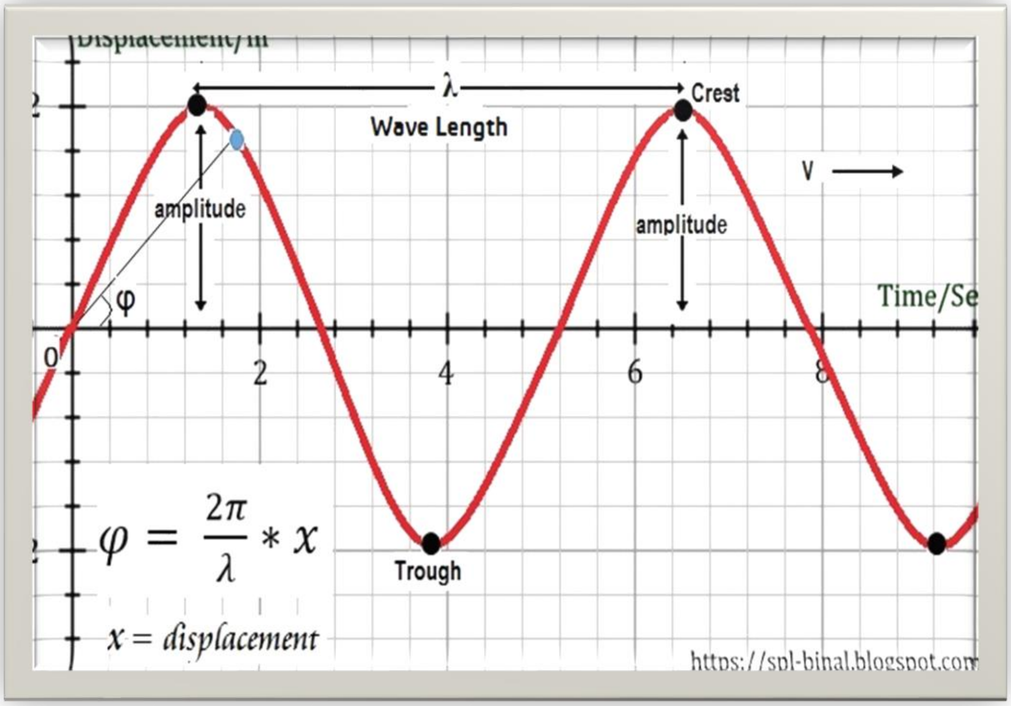
Learning Outcomes

The students will:

• Describe simple examples of free oscillations.
• Describe necessary conditions for execution of simple harmonic motions.
• Describe that when an object moves in a circle, the motion of its projection on the diameter of the circles is SHM.
• Define the terms amplitude, period, frequency, angular frequency and phase difference and express the period
in terms of both frequency and angular frequency.
• Identify and use the equation; a= - ω2x as the defining equation of SHM.
• Prove that the motion of mass attached to a spring is SHM.
• Describe the interchanging between kinetic energy and potential energy during SHM.
• Analyze the motion of a simple pendulum is SHM and calculate its time period.
• Describe practical examples of free and forced oscillations (resonance).
• Describe graphically how the amplitude of a forced oscillation changes with frequency near to the natural frequency of the system.
• Describe practical examples of damped oscillations with particular reference to the efforts of the degree of damping and the importance of critical damping in cases such as a car suspension system

Unit 08

Waves

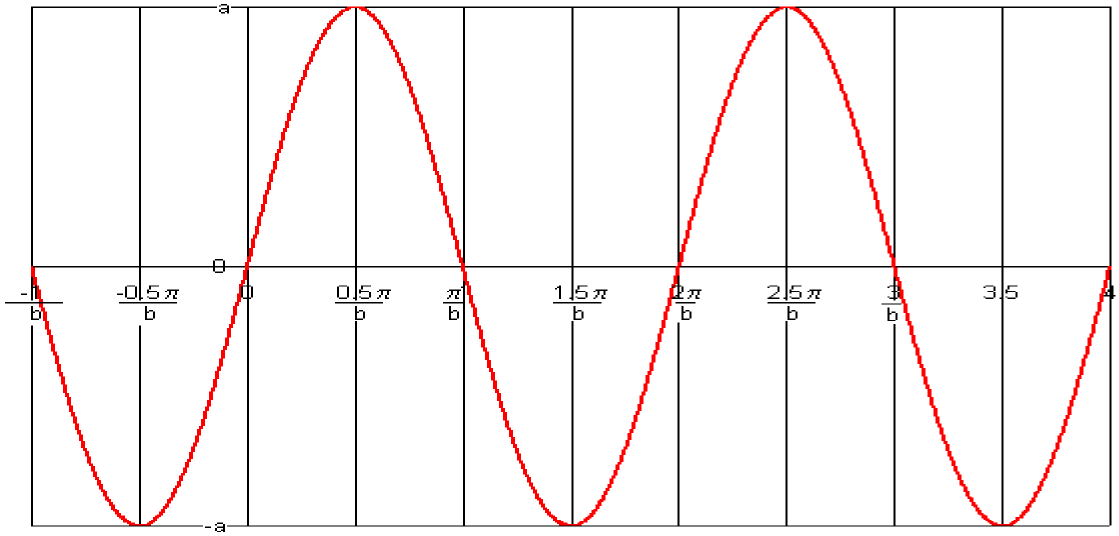


Topics	Understandings	Skills
• Periodic waves • Progressive waves • Transverse and longitudinal waves • Speed of sound in air • Newton's formula and Laplace correction • Superposition of waves • Stationary waves • Modes of vibration of strings • Fundamental mode and harmonics • Vibrating air columns and organ pipes • Doppler effect and its applications • Generation, detection and use of ultrasonic	The students will: • Describe what is meant by wave motion as illustrated by vibrations in ropes, springs and ripple tank. • Demonstrate that mechanical waves require a medium for their propagation while electromagnetic waves do not. • Define and apply the following terms to the wave model; medium, displacement, amplitude, period, compression, rarefaction, crest, trough, wavelength, velocity. • Solve problems using the equation: $v = f\lambda$. • Describe that energy is transferred due to a progressive wave. • Identify that sound waves are	The students will: • Investigate, sketch and interpret the behaviour of wave fronts as they reflect, refract, and diffract by observing (i) Pond ripples / ocean waves / harbour waves amusement park waves pools. • Determine frequency of A.C. by Melde's apparatus/electric sonometer. • Investigate the laws of vibration of stretched strings by sonometer or electromagnetic method. • Determine the wavelength of sound in air using stationary waves and to calculate the speed of sound using resonance tube. • Study the interference of ultrasonic waves in a Young's experiment arrangement and determine the wavelength of ultrasonic waves.

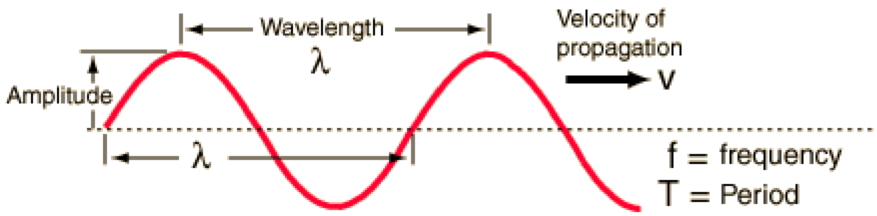
	vibrations of particles in a medium. • Compare transverse and longitudinal waves. • Explain that speed of sound depends on the properties of medium in which it propagates and describe Newton's formula of speed of waves. • Describe the Laplace correction in Newton's formula for speed of sound in air. • Identify the factors on which speed of sound in air depends. • Describe the principle of superposition of two waves from coherent sources. • Describe the phenomenon of interference of sound waves. • Describe the phenomenon of formation of beats due to interference of non coherent sources. • Explain the formation of stationary waves using graphical method • Define the terms, node and antinodes. • Describe modes of vibration of strings. • Describe formation of stationary waves in vibrating air columns. • Explain the observed change in frequency of a mechanical wave coming from a moving object as it approaches and moves away (i.e. Doppler effect). • Explain that Doppler effect is also applicable to e.m. waves. • Explain the principle of the generation and detection of ultrasonic waves using piezoelectric transducers. • Explain the main principles behind the use of ultrasound to obtain diagnostic information about internal structures.	
Unit overview		

Periodic Wave

A periodic wave is a wave with a repeating continuous pattern which determines its wavelength and frequency. It is characterized by the amplitude, a period and a frequency. Amplitude wave is directly related to the energy of a wave, it also refers to the highest and lowest point of a wave. Period defines as time required to complete cycle of a waveform and frequency is number of cycles per second of time.

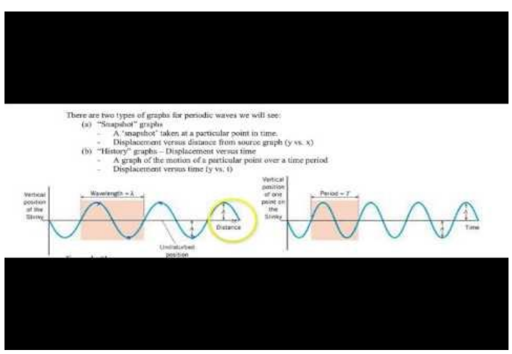


Periodic Wave Relationships



The relationship "distance = velocity x time" is the basic wave relationship. With the wavelength as distance, this relationship becomes $\lambda = vT$. Then using $f = 1/T$ gives the standard wave relationship.

Videos



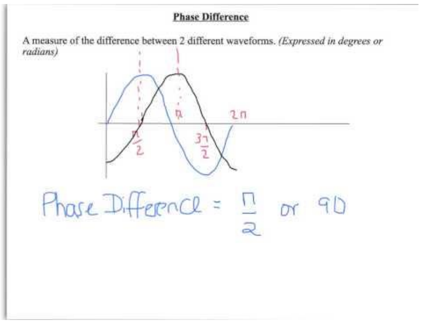
Reference pages

https://www.eeweb.com/profile/andrew-carter/articles/periodic-wave

Progressive waves

A wave which travels continuously in a medium in the same direction without the change in its amplitude is called a travelling wave or a progressive wave.

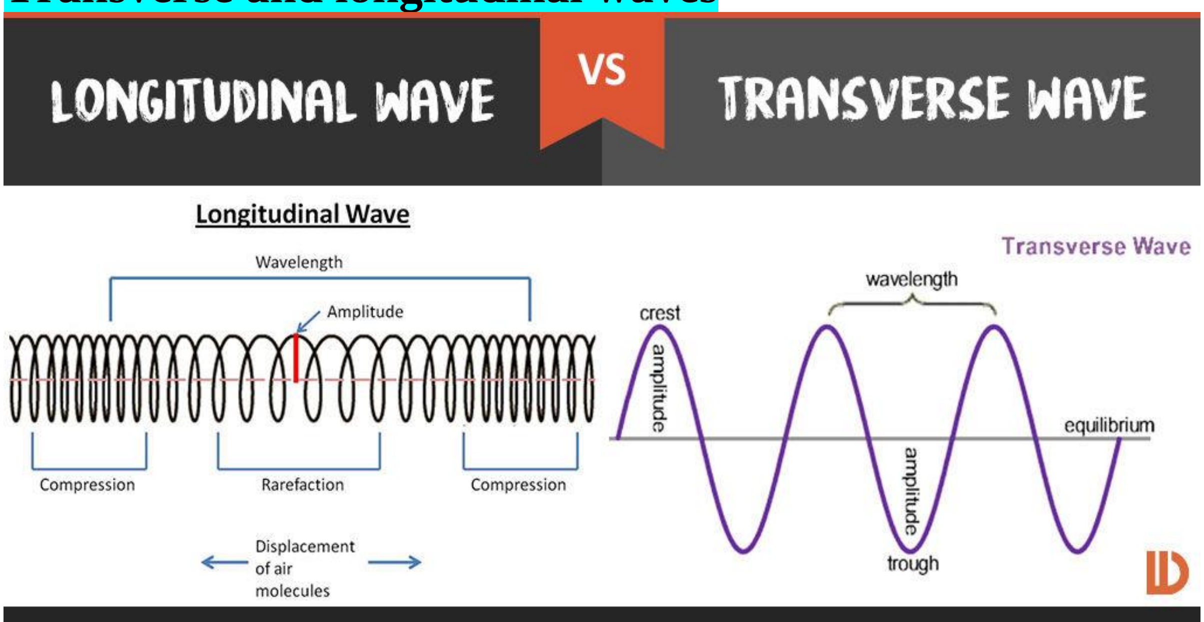
Video



Reference

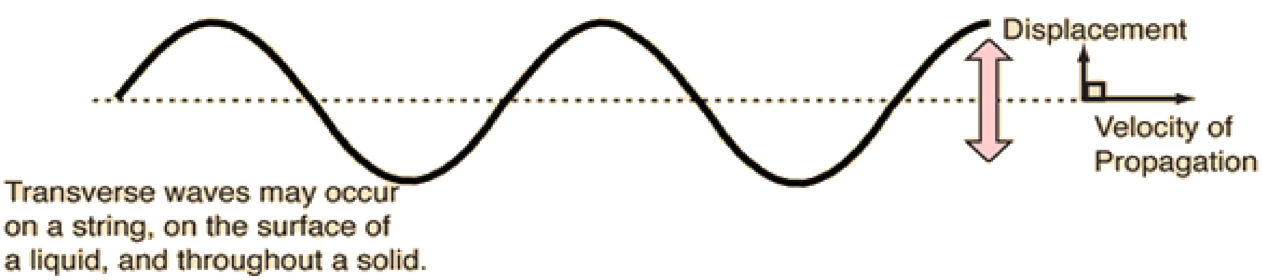
https://byjus.com/physics/progressive-wave/

Transverse and longitudinal waves



Transverse Waves

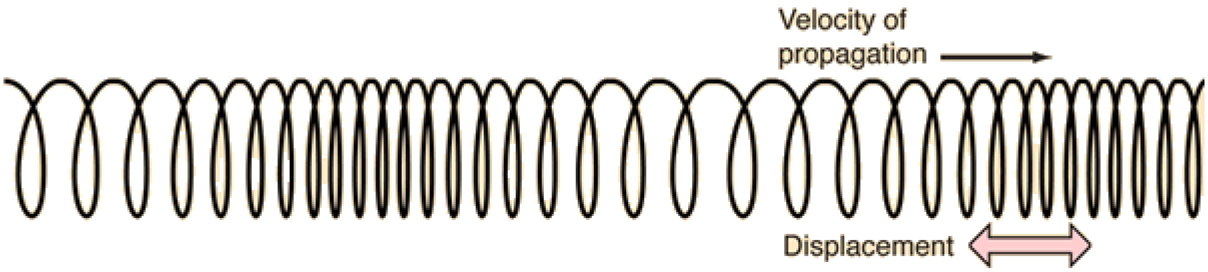
For transverse waves the displacement of the medium is perpendicular to the direction of propagation of the wave. A ripple on a pond and a wave on a string are easily visualized transverse waves.



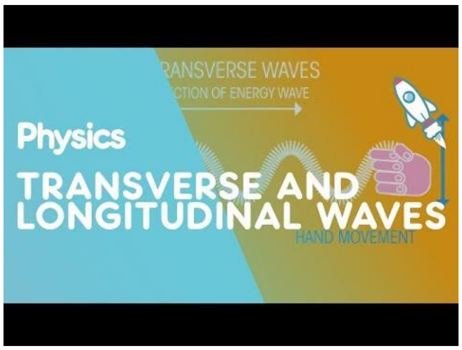
Transverse waves cannot propagate in a gas or a liquid because there is no mechanism for driving motion perpendicular to the propagation of the wave.

Longitudinal Waves

In longitudinal waves the displacement of the medium is parallel to the propagation of the wave. A wave in a "slinky" is a good visualization. Sound waves in air are longitudinal waves.



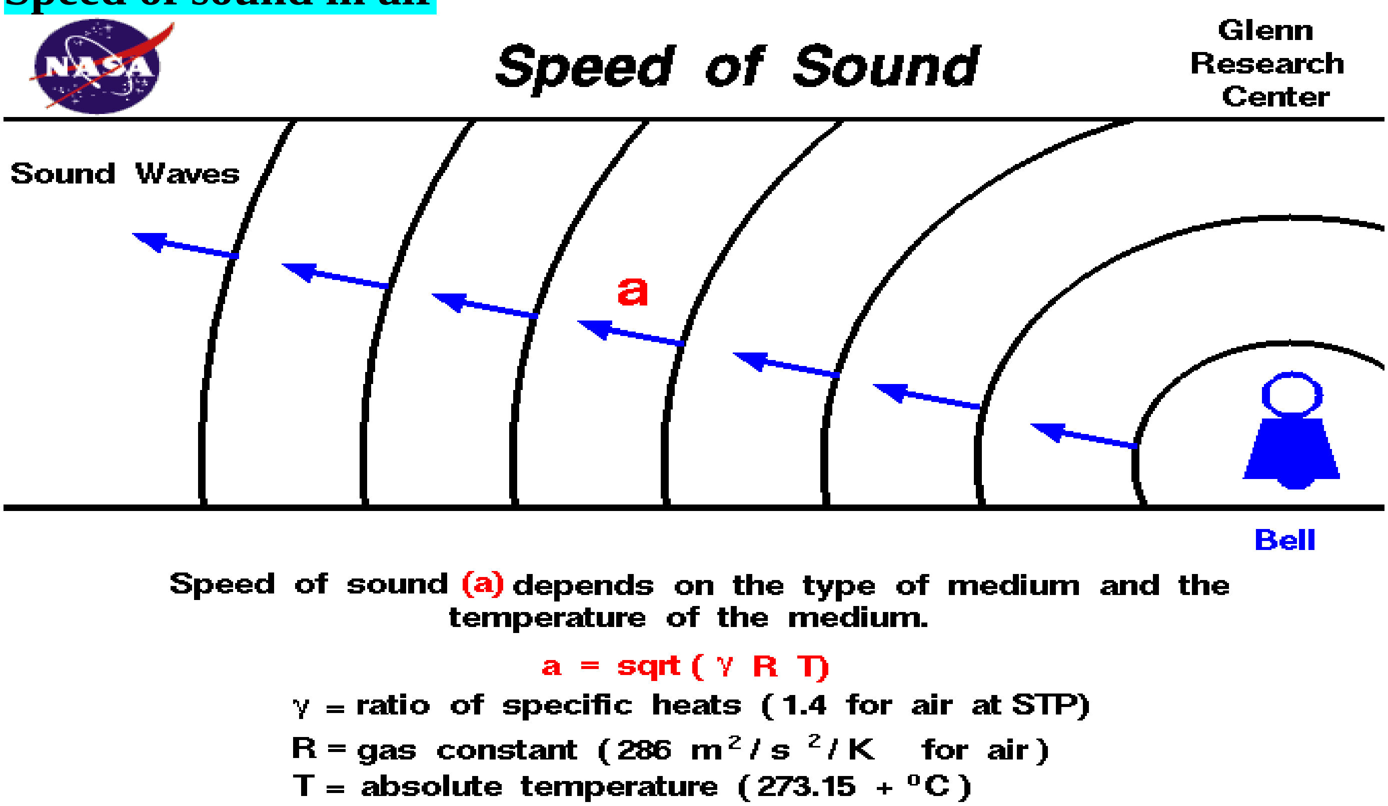
Video



Reference

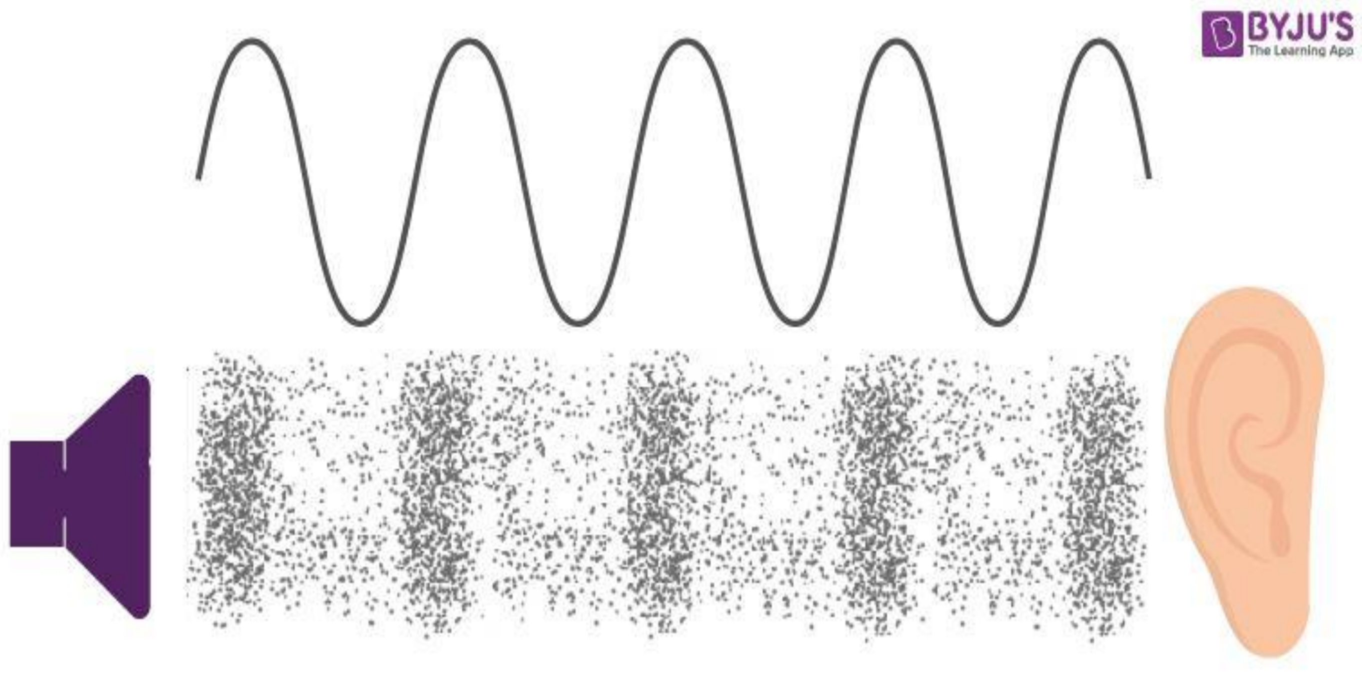
http://hyperphysics.phy-astr.gsu.edu/hbase/Sound/tralon.html

Speed of sound in air



Speed of sound in air

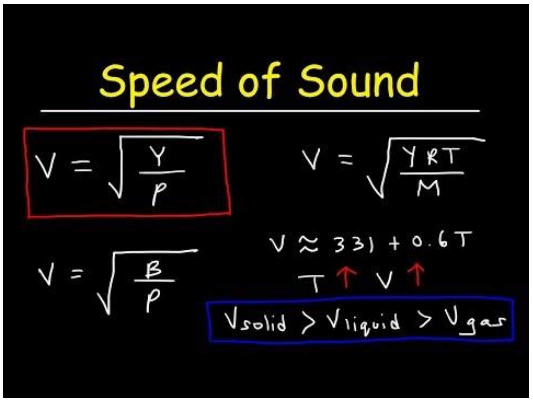
The speed of sound is an essential parameter used in a variety of field in Physics. ***The speed of sound refers to the distance travelled per unit time by a sound wave propagating through a medium***. The speed of sound in air at 20°C is 343.2 m/s which translates to 1,236 km/h.



Propagation of sound through fluids. The places with high density of balls is experiencing Compression and the empty spaces in between are undergoing Rarefaction. The wavelength is the graph of the pressure variation.

The speed of sound in gases is proportional to the square root of the absolute temperature (measured in Kelvin) but it is independent of the frequency of the sound wave or the pressure and the density of the medium. But none of the gases we find in real life are ideal gases and this causes the properties to slightly change.

Video



Reference

https://byjus.com/physics/speed-of-sound-propagation/

Newton’s formula and Laplace correction

Newtons formula for the speed of sound

Newtons worked on the propagation of sound waves through the air. He assumed that this process of propagation is isothermal. Absorption and release of heat during compression and rarefaction will be balanced, thus, the temperature remains constant throughout the process.

According to Boyle’s law

PV = Constant

Where,

P is pressure

V is the volume of gas.

On differentiating above equation we get-

PdV+VdP=0

⇒ PdV = -VdP

$\Rightarrow P = -VdPdV = dP - (dV/V)$

⇒ P = B

Where, $B = dP/-(dV/V)$ is bulk modulus of air.

The velocity of the sound wave can be written as –

$v = \sqrt{B/\rho}$

Thus substituting B =P we get-

$v = \sqrt{P/\rho}$

Speed of sound in air

At Normal Temperature and Pressure, the velocity of sound in air is given by –

$v = \sqrt{P/\rho}$

Where atmospheric pressure $P = 1.1013\times10^5$ N/m^2

The density of air (ρ)= 1.293 kg/m^3

$v = \sqrt{P/\rho} = \sqrt{(1.013\times10^5/1.293)} = 280 m/s$

The value got here does not match with the experimental value. That is 332m/s. Which implies that some correction should be done to Newton’s equation.

Laplace Correction for Newton’s Formula

He corrected the Newtons formula by assuming that, there is no heat exchange takes place as the compression and rarefaction takes place very fast. Thus, the temperature does not remain constant and the propagation of the sound wave in air is an adiabatic process.

For an adiabatic process

PV^γ = Constant

Where,

γ is adiabatic index $\gamma = C p / C v$

C_p specific heat for constant pressure

C_v specific heat for constant volume.

Differentiating both the sides we get-

$$V^{\gamma} dP + P\gamma V^{\gamma-1} dV = 0$$

Dividing both the sides by $V^{\gamma-1}$

$$VdP + P\gamma VdV = 0 \; P\gamma = -\frac{dP}{\left(\frac{dV}{V}\right)} = B$$

The velocity of sound is given by

$$v = \sqrt{\frac{B}{\rho}}$$

Substituting B= γP in above equation we get-

Velocity of sound formula

$$v = \sqrt{\frac{\gamma P}{\rho}}$$

Velocity of sound

Calculate the velocity of sound wave using Laplace correction to Newton's formula at Normal Temperature and Pressure.

Velocity of the sound formula is given by-

$v = \sqrt{(\gamma P/\rho)}$

Where,

Adiabatic index γ – 1.4

Where atmospheric pressure P = 1.1013×10^{5} N/m^{2}

The density of air (ρ)= 1.293 kg/m^{3}

Substituting the values in the equation we get-

$v = \sqrt{(\gamma P/\rho)} = \sqrt{(1.4\times1.013\times10^{5}/1.293)} = 332 m/s$

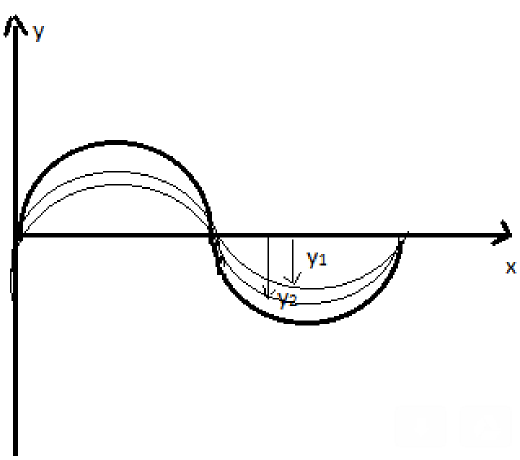
Which has a very good match with the experimental value

Reference

https://byjus.com/physics/laplace-correction/

Superposition of waves

According to the principle of superposition. The resultant displacement of a number of waves in a medium at a particular point is the vector sum of the individual displacements produced by each of the waves at that point.



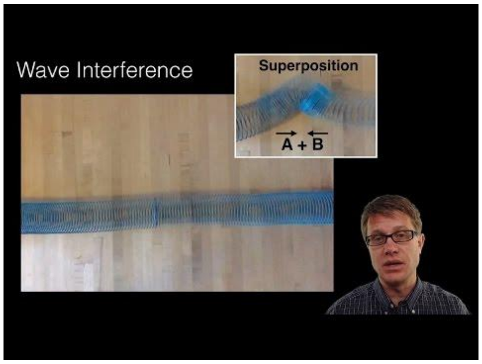
Principle of Superposition

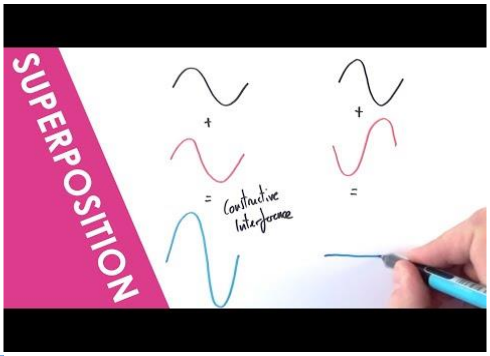
Principle of Superposition of Waves

Considering two waves, travelling simultaneously along the same stretched string in opposite directions as shown in the figure above. We can see images of waveforms in the string at each instant of time. It is

observed that the net displacement of any element of the string at a given time is the algebraic sum of the displacements due to each wave.
Let us say two waves are travelling alone and the displacements of any element of these two waves can be represented by $y_1(x, t)$ and $y_2(x, t)$. When these two waves overlap, the resultant displacement can be given as $y(x,t)$.
Mathematically, $y(x, t) = y_1(x, t) + y_2(x, t)$
As per the principle of superposition, we can add the overlapped waves algebraically to produce a resultant wave. Let us say the wave functions of the moving waves are
$y_1 = f1(x–vt)$,
$y_2 = f2(x–vt)$
……….
$y_n = f_n(x–vt)$
then the wave function describing the disturbance in the medium can be described as
$y = f_1(x – vt)+ f_2(x – vt)+ …+ f_n(x – vt)$
or, $y=\sum$ i=1 to n = fi (x−vt)
Let us consider a wave travelling along a stretched string given by, $y_1(x, t) = A \sin(kx – \omega t)$ and another wave, shifted from the first by a phase φ, given as $y_2(x, t) = A \sin(kx – \omega t + \varphi)$
From the equations we can see that both the waves have the same angular frequency, same angular wave number k, hence the same wavelength and the same amplitude A.
Now, applying the superposition principle, the resultant wave is the algebraic sum of the two constituent waves and has displacement $y(x, t) = A \sin(kx – \omega t) + A \sin(kx – \omega t + \varphi)$
As, $\sin A = \sin B = 2\sin (A+B)/2 . \cos (A−B)/2$
The above equation can be written as,
$y(x, t) = [2A \cos 1/2\ \phi] \sin (kx − wt + 1/2\phi)$
The resultant wave is a sinusoidal wave, travelling in the positive X direction, where the phase angle is half of the phase difference of the individual waves and the amplitude as $[2\cos 1/2\phi]$ times the amplitudes of the original waves.

Videos



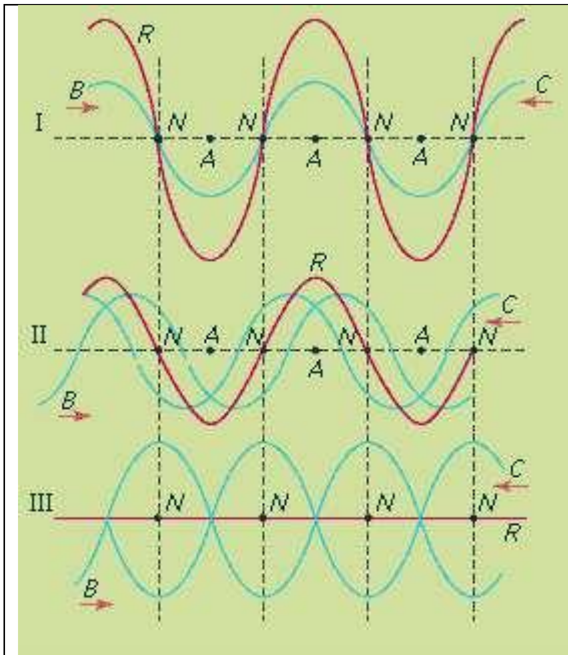


Reference

https://byjus.com/jee/superposition-of-waves/

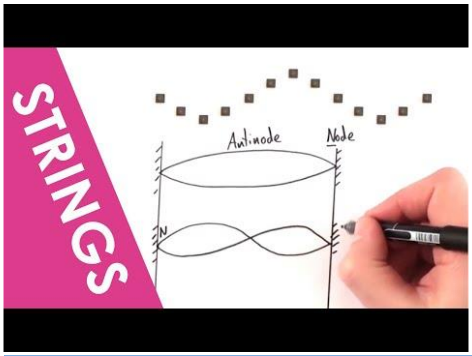
Stationary waves

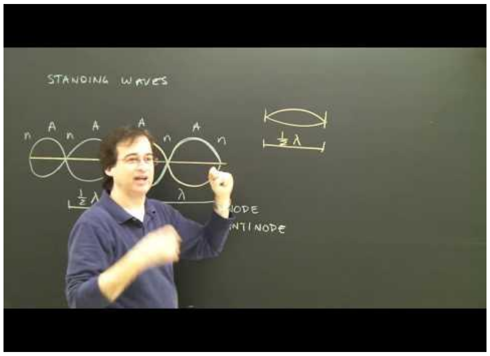
Standing wave, also called stationary wave, combination of two waves moving in opposite directions, each having the same amplitude and frequency. The phenomenon is the result of interference; that is, when waves are superimposed, their energies are either added together or canceled out. In the case of waves moving in the same direction, interference produces a traveling wave. For oppositely moving waves, interference produces an oscillating wave fixed in space.



fixed nodes in a standing wave

Videos





Reference
https://www.britannica.com/science/standing-wave-physics

Modes of vibration of strings

The frequencies at which standing waves can be set up on a string are the string's natural frequencies. They can be determined quite easily. The first thing to note is that the end of the string being held by the person is tightly gripped so any pulse or wave that returns to the person's hand will be reflected and inverted. Therefore both ends of the string can be considered to be fixed and so must be at nodes of the standing wave. But you learned earlier that the distance between adjacent nodes is half a wavelength. So, the length of the string must be an exact number of half wavelengths. That is, the string must be one half wavelength long, two half wavelengths long (i.e. one whole wavelength long), three half wavelengths long, four half wavelengths long (i.e. two whole wavelengths long), etc. If the length of the string is denoted by *L* and the wavelength by λ, then this can be expressed in the following way:

$$L = \frac{1}{2}\lambda \text{ or } \lambda \text{ or } \frac{3}{2}\lambda \text{ or } 2\lambda \text{ or } \ldots$$

This can be written more concisely as:

$$L = \frac{n\lambda}{2}$$

where *n* is an integer number (i.e. 1, 2, 3, 4, …).

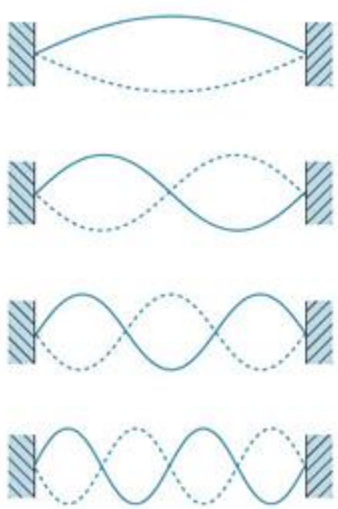
Rearranging this equation, we can show that the wavelengths of standing waves that can be set up on the string are therefore given by:

$$\lambda = \frac{2L}{n}$$

However, the frequency of a wave is related to its wavelength by the expression $f = v/\lambda$, where v is the wave speed. Therefore, the natural frequencies for the string are given by:

$$f = \frac{nv}{2L}$$

The different standing-wave patterns, known as **normal modes of vibration**.The solid and dashed lines indicate the positions of the string at opposite phase positions in the cycle. You should be able to see that for each normal mode the string contains an integer number of half wavelengths.



mode	wavelength	frequency
first	$2L$	$\frac{v}{2L}$
second	L	$\frac{v}{L}$
third	$\frac{2L}{3}$	$\frac{3v}{2L}$
fourth	$\frac{L}{2}$	$\frac{2v}{L}$

The first four normal modes of vibration of a string fixed at each end. The solid and dashed lines indicate the positions of the string at opposite phase positions in the cycle

In the first mode ($n = 1$) there are nodes at either end of the string but no nodes elsewhere on the string. The frequency at which this standing-wave pattern will be set up is $f = v/2L$. The first mode is known as the **fundamental mode** and, for this reason, the first natural frequency tends to be referred to as the

fundamental frequency.

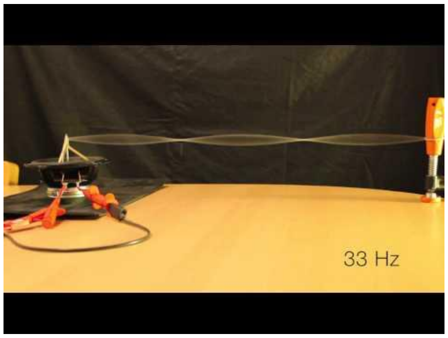
In the second mode ($n = 2$) there are again nodes at either end of the string but now there is also a node in the middle of the string. The frequency at which this standing-wave pattern will be set up is $f = v/L$. This is twice the value of the fundamental frequency.

In the third mode ($n = 3$) there are nodes at either end of the string and two more nodes positioned along the string. The frequency at which this standing-wave pattern will be set up is $f = 3v/2L$. This is three times the value of the fundamental frequency.

In the fourth mode ($n = 4$) there are the anticipated nodes at either end of the string and three more positioned at equal distances along the string. The frequency at which this standing-wave pattern will be set up is $f = 2v/L$. This is four times the value of the fundamental frequency.

You may well be seeing a trend emerging here! The frequencies at which standing waves are set up on the string are harmonically related. If the frequency at which the first mode occurs is denoted f_1, then the frequencies at which the second, third and fourth modes occur are $2f_1$, $3f_1$ and $4f_1$ respectively. This set of frequencies and its indefinite continuation ($5f_1$, $6f_1$, $7f_1$ …) is known as a harmonic series. The fact that its natural frequencies form a harmonic series makes the vibrating string one of the most useful means of producing musical sounds

Video

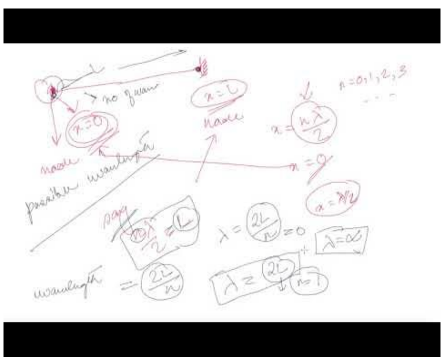


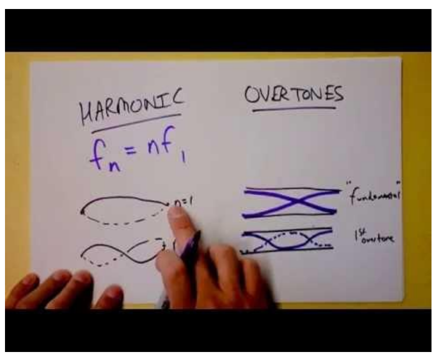
Reference
https://www.open.edu/openlearn/science-maths-technology/engineering-and-technology/technology/creating-musical-sounds/content-section-5.4

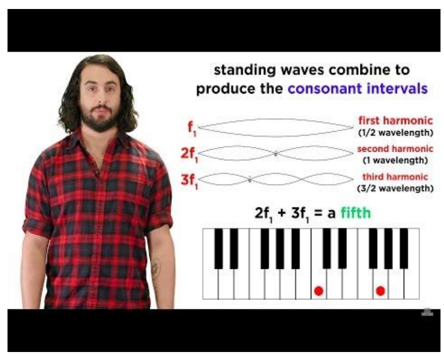
Fundamental mode and harmonics.

The lowest resonant frequency of a vibrating object is called its fundamental frequency. Most vibrating objects have more than one resonant frequency and those used in musical instruments typically vibrate at harmonics of the fundamental. A harmonic is defined as an integer (whole number) multiple of the fundamental frequency. Vibrating strings, open cylindrical air columns, and conical air columns will vibrate at all harmonics of the fundamental. Cylinders with one end closed will vibrate with only odd harmonics of the fundamental. Vibrating membranes typically produce vibrations at harmonics, but also have some resonant frequencies which are not harmonics. It is for this class of vibrators that the term overtone becomes useful - they are said to have some non-harmonic overtones.
The nth harmonic = n x the fundamental frequency.

Video





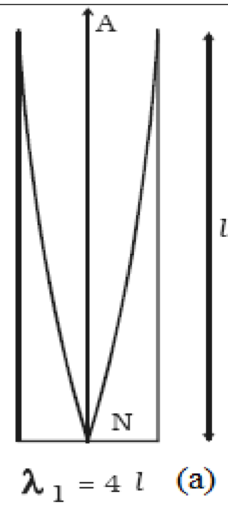


Reference
http://hyperphysics.phy-astr.gsu.edu/hbase/Waves/funhar.html

Vibrating air columns and organ pipes

Vibrations of Air Column in Pipes

Musical wind instruments like flute, clarinet etc. are based on the principle of vibrations of air columns. Due to the superposition of the incident wave and the reflected wave, longitudinal stationary waves are formed in the pipe.



Stationary waves in a closed pipe (Fundamental mode)

Organ pipes

Organ pipes are musical instruments which are used to produce musical sound by blowing air into the pipe. Organ pipes are two types (a) closed organ pipes, closed at one end (b) open organ pipe, open at both ends.

(a) Closed organ pipe

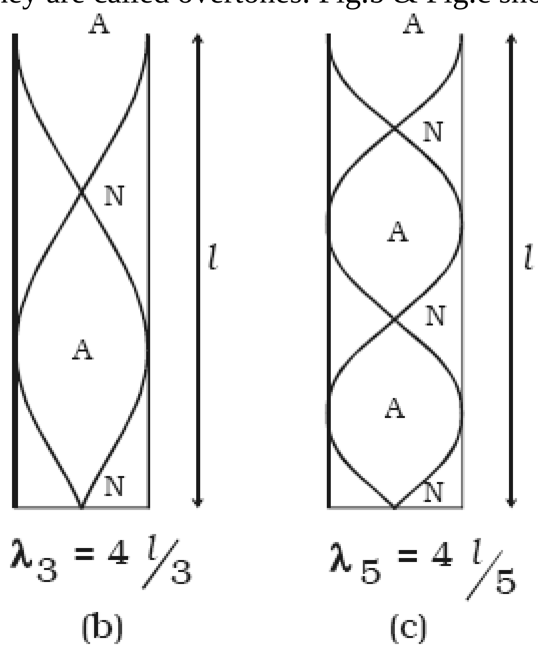
If the air is blown lightly at the open end of the closed organ pipe, then the air column vibrates (as shown in figure) in the fundamental mode. There is a node at the closed end and an antinode at the open end. If l is the length of the tube,

$l = \lambda_1/4$ or $\lambda_1 = 4l$ …... (1)

If n_1 is the fundamental frequency of the vibrations and v is the velocity of sound in air, then

$n_1 = v/\lambda_1 = v/4l$ …... (2)

If air is blown strongly at the open end, frequencies higher than fundamental frequency can be produced. They are called overtones. Fig.b & Fig.c shows the mode of vibration with two or more nodes and antinodes.



Overtones in a closed pipe

$l = 3\lambda_3/4$ or $\lambda_3 = 4l/3$ …... (3)

Thus, $n_3 = v/\lambda_3 = 3v/4l = 3n_1$ …... (4)

This is the first overtone or third harmonic.

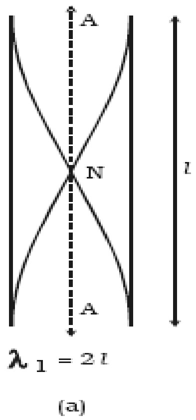
Similarly, $n_5 = 5v/4l = 5n_1$ …... (5)

This is called as second overtone or fifth harmonic.

Therefore the frequency of pth overtone is $(2p + 1)\, n_1$ where n_1 is the fundamental frequency. In a closed pipe only odd harmonics are produced. The frequencies of harmonics are in the ratio of 1 : 3 : 5.....

(b) Open organ pipe

When air is blown into the open organ pipe, the air column vibrates in the fundamental mode as shown in figure. Antinodes are formed at the ends and a node is formed in the middle of the pipe. If *l* is the length of the pipe, then



Stationary waves in an open pipe

$l = \lambda_1/2$ Or $\lambda_1 = 2l$ …... (1)

$v = n_1\lambda_1 = n_1 2l$

The fundamental frequency,

$n_1 = v/2l$ …... (2)

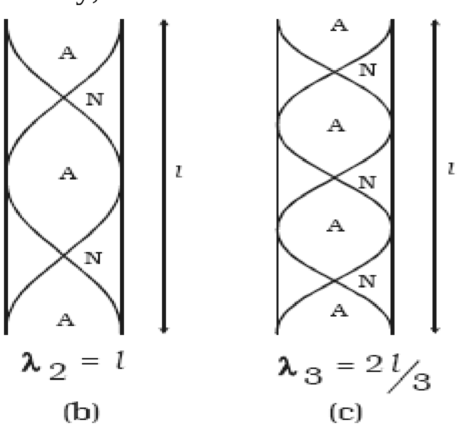
In the next mode of vibration additional nodes and antinodes are formed as shown in Fig.b and Fig.c.

$l = \lambda_2$ or $v = n_2\lambda_2 = n_2\,(l)$

So, $n_2 = v/l = 2n_1$ …... (3)

This is the first overtone or second harmonic.

Similarly,



Overtones in an open pipe

$n_3 = v/\lambda_3 = 3v/2l = 3n_1$ …... (4)

This is the second overtone or third harmonic. Therefore the frequency of P^{th} overtone is $(P + 1)\, n_1$ where n_1 is the fundamental frequency.

The frequencies of harmonics are in the ratio of 1 : 2 : 3 ....

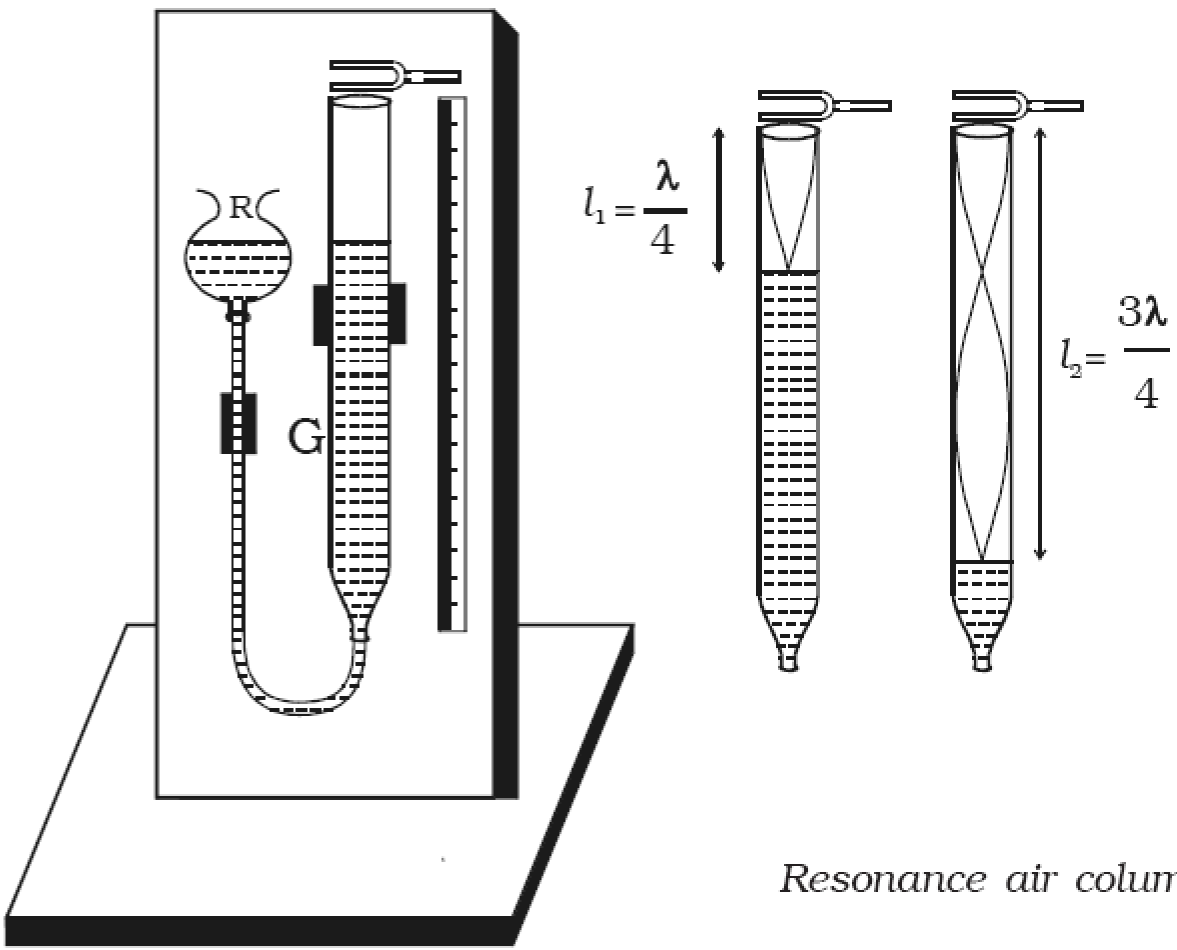
Resonance air column apparatus

The resonance air column apparatus consists of a glass tube G about one metre in length (as shown in figure) whose lower end is connected to a reservoir R by a rubber tube.

The glass tube is mounted on a vertical stand with a scale attached to it. The glass tube is partly filled with water. The level of water in the tube can be adjusted by raising or lowering the reservoir.

A vibrating tuning fork of frequency n is held near the open end of the tube. The length of the air column is adjusted by changing the water level. The air column of the tube acts like a closed organ pipe. When this air column resonates with the frequency of the fork the intensity of sound is maximum.

Here longitudinal stationary wave is formed with node at the water surface and an antinode near the open end. If l1 is the length of the resonating air column.



Resonance air column apparat

$\lambda/4 = l_1 + e$ …... (1)

where e is the end correction.

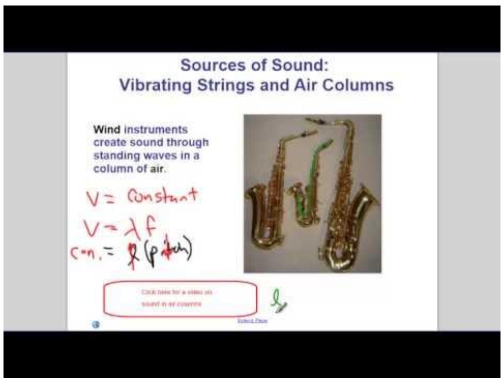
The length of air column is increased until it resonates again with the tuning fork. If l_2 is the length of the air column.

$3\lambda/4 = l_2 + e$ …... (2)
From equations (1) and (2)
$\lambda/2 = (l_2 - l_1)$ …... (3)
The velocity of sound in air at room temperature
$v = n\lambda = 2n\,(l_2 - l_1)$ …... (4)

End correction

The antinode is not exactly formed at the open end, but at a small distance above the open end. This is called the end correction.
As $l_1 + e = \lambda/4$ and $l_2 + e = 3\lambda/4$
$e = (l_2 - 3l_1)/2$
It is found that $e = 0.61r$, where r is the radius of the glass tube.

Video



Reference
https://www.askiitians.com/iit-jee-wave-motion/vibrations-of-air-column-in-pipes/

Doppler effect and its applications

When an ambulance crosses you with its siren blaring, you hear the pitch of the siren change: as it approaches, the siren's pitch sounds higher than when it is moving away from you. This change is a common physical demonstration of the Doppler effect. But, have you taken the time to understand the phenomenon of the Doppler effect and its causes? If the answer is NO, then read on the article to understand clearly and answer any given questions on Doppler effect in exams.

How is the Doppler Effect Defined?

Doppler effect is an important phenomenon that is useful in a variety of different scientific disciplines, including planetary science: Astronomers rely on the Doppler effect to detect planets outside of our solar system or exoplanets. The Doppler effect or the Doppler shift describes the change in frequency of any kind of sound or light wave produced by a moving source with respect to an observer. Waves emitted by a source travelling towards an observer gets compressed. In contrast, waves emitted by a source travelling away from an observer get stretched out. We can define the Doppler effect as
Doppler Effect is an increase (or decrease) in the frequency of sound, light, or other waves as the source and observer move towards (or away from) each other.
Many mistake Doppler effect to be applicable only for sound waves. It should be noted that the Doppler effect doesn't just apply to sound. It works with all types of waves including light. Edwin Hubble used the Doppler effect to determine that the universe is expanding. Hubble found that the light from distant galaxies was shifted toward lower frequencies, to the red end of the spectrum. This is known as a red Doppler shift or a red-shift. If the galaxies were moving toward Hubble, the light would have been blue-shifted. Doppler radars also help meteorologists learn about possible tornadoes

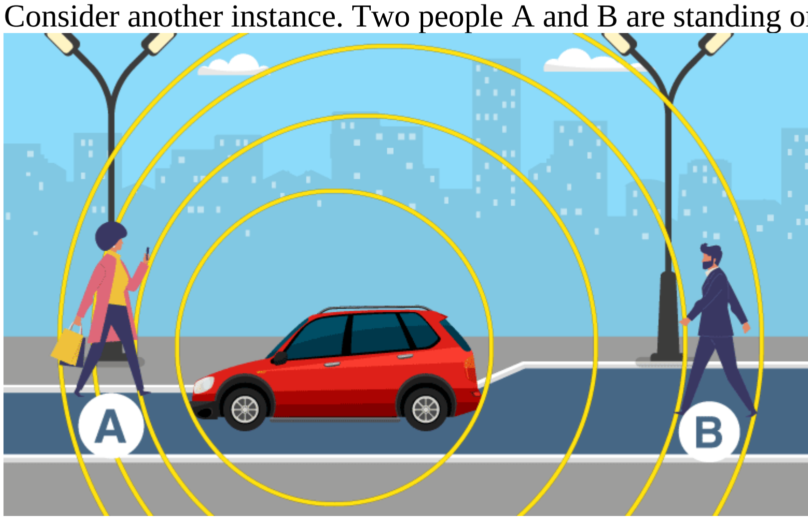
Discovery of Doppler Effect

Doppler was the son of a stonemason, who went on to become a celebrated academic and scientist. After school young Christian studied astronomy and mathematics in Salzburg and Vienna, and at the age of 38 went on to work at the Prague Polytechnic in Czechoslovakia. Only a year later, he found fame by discovering that the observed frequency of light and sound waves is affected by the relative motion of the source and the detector (in other words their positions in relation to one another)–and this became known as the Doppler Effect. On 17 March 1853, at the age of only 49, Christian Doppler died from respiratory disease in Venice.

Understanding Doppler Effect In Real Life

To understand the Doppler effect let us imagine the following scene. You are standing beside a road and a police car with its siren turned on, drives by you. What do you notice about the sound? The siren's sound isn't so loud when it is at a distance, which then reaches a maximum when it is just beside you, diminishing again as it crosses and moves away from you.

Consider another instance. Two people A and B are standing on the road as shown below in the picture.



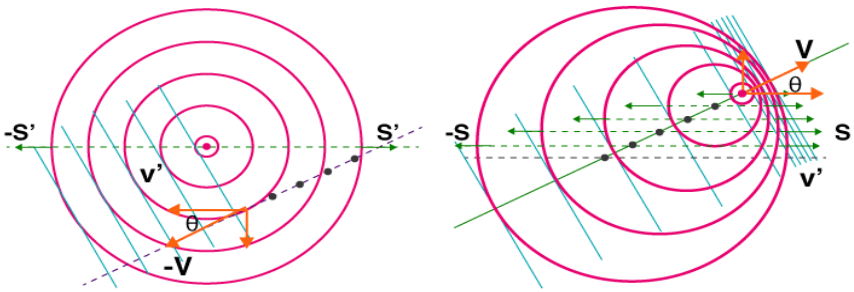
Which person do you think hears the sound of the revving engine with a greater magnitude? You know that its person A. But why?

This is where we discuss the Doppler Effect or Doppler Shift. To highlight this effect you should understand the difference between the two situations given below.

Situation 1: How is the pattern of waves formed when you suddenly jump into a pond?

Situation 2: How is the pattern of waves formed when you are walking in a pond?

The image given below highlights the difference between wave patterns in both situations.



This difference is because the source of the waves in the second case moves. This is what the Doppler Effect is. It is named after the physicist Christian Doppler who proposed this in the 19th century. The Doppler effect is the change of frequency of a wave emitted as observed by an observer moving relative to the source. In this, the frequency received by the observer is higher during the approach, identical when the relative positions are the same, and keeps lowering on the recession of source. If both the source and observer are moving, the total Doppler Effect is calculated based on both these motions.
Let us say that light waves travel from a source to an observer. In this case, the wave travels the fixed distance across which the source and the observer are located. But there are cases when either of the two is moving, that is, the source is moving relative to the observer, or vice versa. It is in these scenarios that the Doppler effect comes into the picture.

Doppler Effect Formula

In physics, where the speed of the receiver and the source relative to the medium are lower than the velocity of waves, the relationship between emitted frequency f_0 and observed frequency f is given by:

$f=(c\pm vrc\pm vs)f0$

Where
c is the velocity of waves in the medium
v_r is the velocity of the source relative to the medium
v_s is the velocity of the receiver relative to the medium
The frequency decreases if either is moving away from the other.

Applications of Doppler Effect

Some Doppler effect applications are provided in the points mentioned below:
Sirens
Radar
Astronomy
Medical Imaging
Blood Flow Measurement
Satellite Communication
Vibration Measurement
Developmental Biology
Audio
Velocity Profile Measurement

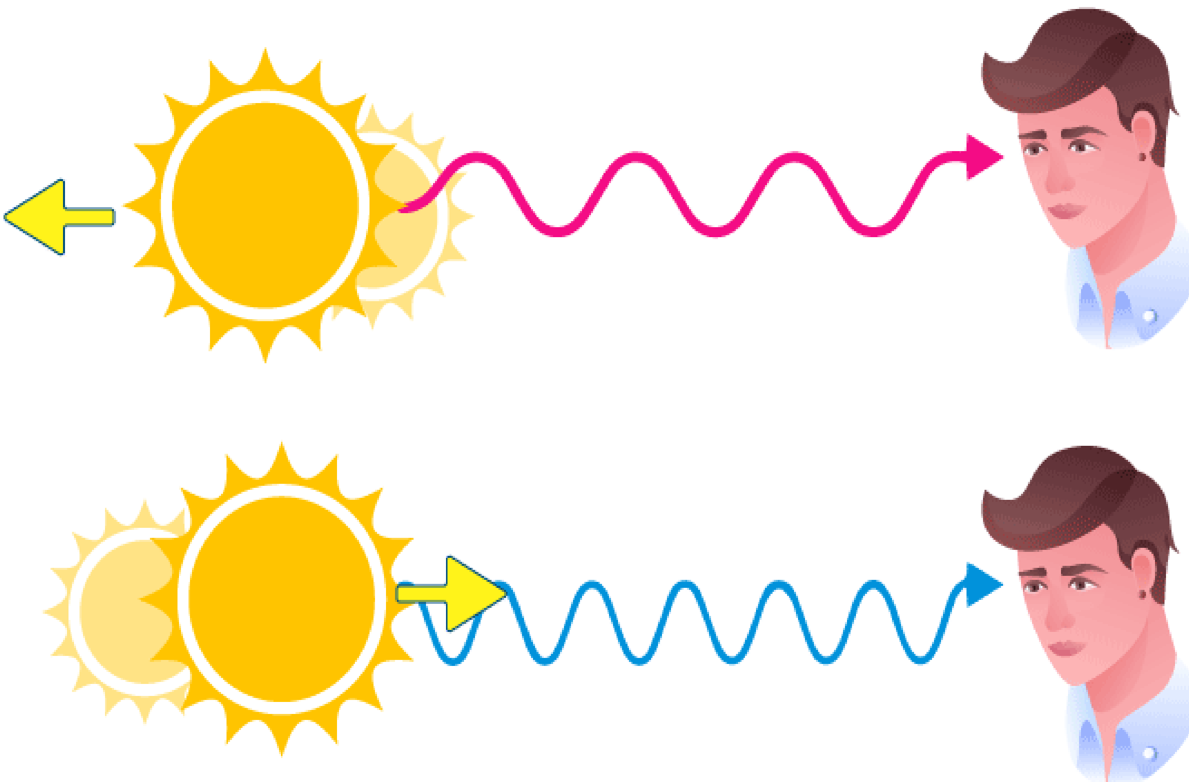
Doppler Effect In Light

The Doppler effect also affects the light which is emitted by other bodies in space. If the body is "red shifted" the light waves are spread apart, and it is travelling away from us while if it is "blue shifted," its light waves are compacted and it is coming towards us. The detailed explanation of the Doppler effect in light is given below.

Red Shift and Blue Shift:

When the light source moves away from the observer, the frequency received by the observer will be less than the frequency transmitted by the source. This causes a shift towards the red end of the visible light spectrum. Astronomers call it as the *redshift*.

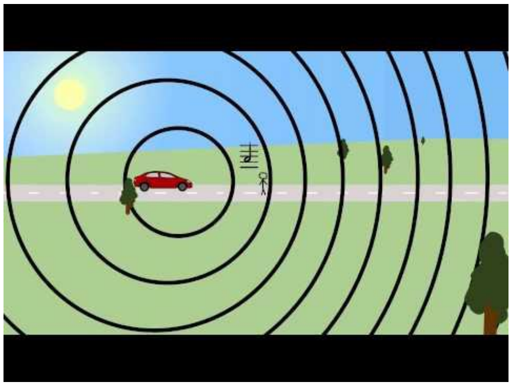
When the light source moves towards the observer, the frequency received by the observer will be greater than the frequency transmitted by the source. This causes a shift towards the high-frequency end of the visible light spectrum. Astronomers call it as the *blue shift*.



Doppler Effect In Sound

For sound waves which propagate in a medium, the velocity of the source and the observer are relative to the medium in which the waves are transmitted. The total Doppler effect may, therefore, result from motion of the observer, motion of the source, or motion of the medium. These effects are separately analyzed.

Video



Reference

https://byjus.com/physics/doppler-effect/

Generation, detection and use of ultrasonic

Physics of Ultrasound

Generation of ultrasonic sound waves

Ultrasound uses ultrasonic (above the range of human hearing) sound waves that are produced and detected within an ultrasound transducer. The physical concept underlying the transducer is the **piezoelectric effect**. This is the property of some materials that causes them to change in shape when an electric current is applied to them. Alternatively, a change in shape can provoke an electric current to form. A ultrasound transducer contains a piece of piezoelectric material between two electrodes. An osciliating current is applied, causing the piezoelectric material to vibrate rapidly and generate ultrasound waves.

Properties of ultrasonic sound waves

Ultrasound waves interact with tissue in various ways.
They are **attenuated** through absorption and scattering.
Absorption occurs due to loss of energy as heat, particularly in tissues that are unable to oscillate (eg. bone)
Scattering occurs with small inhomogeneities (eg. small vessel, soft tissue septa). Some of this scatter returns to the probe, giving the characteristic 'grainy' apperance to ultrasound images
Waves may be reflected or refracted, similar to light 'rays' passing through different media
Reflection of the wave returns a signal to the transducer, and occurs at a boundary between two media, perpendicular to the wave direction
Refraction of the wave occurs at oblique angles between two different mediums, and may lead to errors in depth estimation

Detection of ultrasonic waves

Ultrasonic waves which return to the detector, either by reflection or scattering, cause the piezoelectric material to vibrate, generating an electric signal that is converted into an image.

Use of Ultrasound

Ultrasound is a relatively safe imaging procedure, but needs some experience in use before images can be easily read. It is most useful for interstitial or intracavitary brachytherapy, but can also be used in some single-field applications (eg. breast boost).

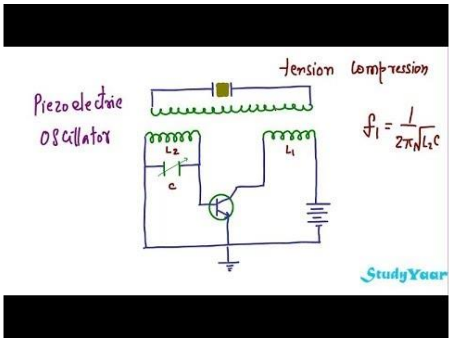
Advantages

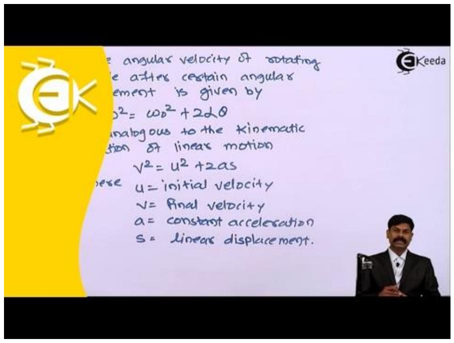
No ionising radiation
Not invasive (with some exceptions, eg. prostate ultrasound may require a rectal probe)
3D or 4D ultrasound is available
Useful in brachytherapy to verify anatomy or location of applicators
Inexpensive

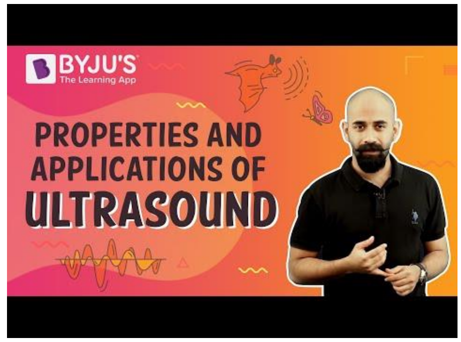
Disadvantages

Gives no information on attenuation coefficients of tissue
Unable to produce DRR
Operator dependent
Limited to certain body sites (unable to scan through bone or gas)
Ultrasound waves are affected by refraction the depth seen on the scan may not be accurate
Poor image resolution due to scattering artefact

Video







Reference

http://ozradonc.wikidot.com/principles-of-ultrasound

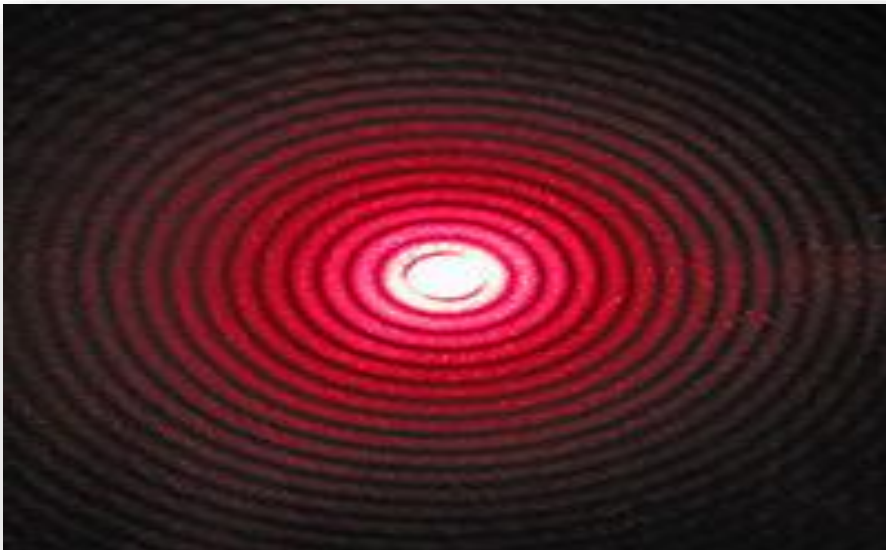
Learning Outcomes

The students will:

- Describe what is meant by wave motion as illustrated by vibrations in ropes, springs and ripple tank.
- Demonstrate that mechanical waves require a medium for their propagation while electromagnetic waves do not.
- Define and apply the following terms to the wave model; medium, displacement amplitude, period, compression, rarefaction, crest, trough, wavelength, velocity.
- Solve problems using the equation: $v = f\lambda$.
- Describe that energy is transferred due to a progressive wave.
- Identify that sound waves are vibrations of particles in a medium.
- Compare transverse and longitudinal waves.
- Explain that speed of sound depends on the properties of medium in which it propagates and describe Newton's formula of speed of waves.
- Describe the Laplace correction in Newton's formula for speed of sound in air.
- Identify the factors on which speed of sound in air depends.
- Describe the principle of superposition of two waves from coherent sources.
- Describe the phenomenon of interference of sound waves.
- Describe the phenomenon of formation of beats due to interference of non coherent sources.
- Explain the formation of stationary waves using graphical method
- Define the terms, node and antinodes.
- Describe modes of vibration of strings.
- Describe formation of stationary waves in vibrating air columns.
- Explain the observed change in frequency of a mechanical wave coming from a moving object as it approaches and moves away (i.e. Doppler effect).
- Explain that Doppler effect is also applicable to e.m. waves.
- Explain the principle of the generation and detection of ultrasonic waves using piezoelectric transducers.
- Explain the main principles behind the use of ultrasound to obtain diagnostic information about internal structures.

Unit – 9

Physical Optics



Topics	Understandings	Skills
• Nature of light • Wave front • Huygen's principle • Interference -Young's double slit experiment -Michleson 's Interferometer • Diffraction • Polarization	The students will: • describe light waves as a part of electromagnetic waves spectrum. • describe the concept of wave front. • state Huygen's principle and use it to construct wave front after a time interval. • state the necessary conditions to observe interference of light. • describe Young's double slit experiment and the evidence it provides to support the wave theory of light. • explain colour pattern due to interference in thin films. • describe the parts and working of Michelson Interferometer and its uses. • explain diffraction and identify that interference occurs between waves that have been diffracted. • describe that diffraction of light is evidence that light behaves like waves.	The students will: • investigate that light can be diffracted but needs a very small slit because the wavelength of light is small. • demonstrate diffraction including the diffraction of water waves in a ripple tank with both a wide gap and a narrow gap. • measure the slit separation/ grating element 'd' of a diffraction grating by using the known wavelength of laser light. • demonstrate the interference, diffraction and polarization of e.m. waves by Using microwave apparatus. • determine the wavelength of light by using a diffraction grating and spectrometer. • measure the diameter of a wire or hair using laser. • determine the pick count of a nylon mesh by using a diffraction grating and laser. • demonstrate polarization of light waves using two Polaroid glasses and LDR and hence, verify Malus' law.

	• describe and explain diffraction at a narrow slit. • describe the use of a diffraction grating to determine the wavelength of light and carry out calculations using $d\sin\theta=n\lambda$. • describe the phenomena of diffraction of X-rays through crystals. • explain polarization as a phenomenon associated with transverse waves. • identify and express that polarization is produced by a Polaroid. • explain the effect of rotation of Polaroid on Polarization. • explain how plane polarized light is produced and detected.	

Chapter overview

Physical Optics

Physical optics is also the name of an approximation commonly used in optics, electrical engineering and applied physics. In this context, it is an intermediate method between geometric optics, which ignores wave effects, and full wave electromagnetism, which is a precise theory. The word "physical" means that it is more physical than geometric or ray optics and not that it is an exact physical theory.
This approximation consists of using ray optics to estimate the field on a surface and then integrating that field over the surface to calculate the transmitted or scattered field. This resembles the Born approximation, in that the details of the problem are treated as a perturbation.
In optics, it is a standard way of estimating diffraction effects. In radio, this approximation is used to estimate some effects that resemble optical effects. It models several interference, diffraction and polarization effects but not the dependence of diffraction on polarization. Since this is a high-frequency approximation, it is often more accurate in optics than for radio.
In optics, it typically consists of integrating ray-estimated field over a lens, mirror or aperture to calculate the transmitted or scattered field.
In radar scattering it usually means taking the current that would be found on a tangent plane of similar material as the current at each point on the front, i. e. the geometrically illuminated part, of a scattered. Current on the shadowed parts is taken as zero. The approximate scattered field is then obtained by an integral over these approximate currents. This is useful for bodies with large smooth convex shapes and for lousy (low-reflection) surfaces.
The ray-optics field or current is generally not accurate near edges or shadow boundaries, unless supplemented by diffraction and creeping wave calculations.
The standard theory of physical optics has some defects in the evaluation of scattered fields, leading to decreased accuracy away from the specular direction. An improved theory introduced in 2004 gives exact solutions to problems involving wave diffraction by conducting scatterers.

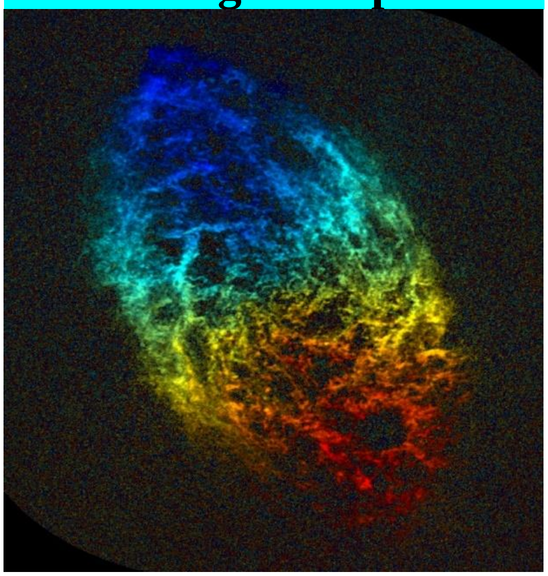
1.Nature of light

INTRODUCTION

Dual nature of light means light has two different nature, sometimes it behaves like a particle sometimes it behaves like a wave.

I discuss a few of the famous experiments which establishes the nature of light i.e. light is a wave or a particle.

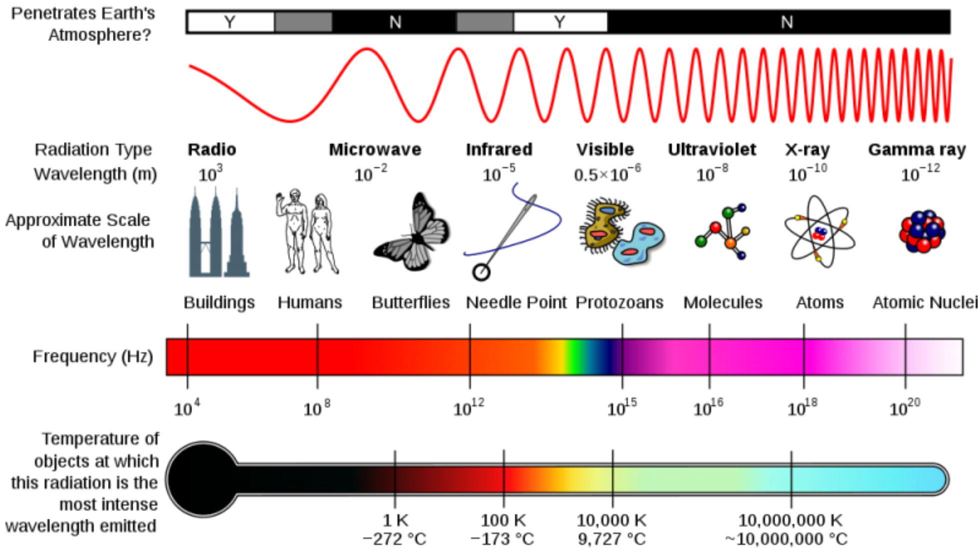
Electromagnetic spectrum



When you think of light, you probably think of what your eyes can see. But the light to which our eyes are sensitive is just the beginning; it is a sliver of the total amount of light that surrounds us.

The electromagnetic spectrum is the term used by scientists to describe the entire range of light that exists. From radio waves to gamma rays, most of the light in the universe is, in fact, invisible to us!

Light is a wave of alternating electric and magnetic fields. The propagation of light isn't much different than waves crossing an ocean. Like any other wave, light has a few fundamental properties that describe it. One is its frequency, measured in hertz (Hz), which counts the number of waves that pass by a point in one second. Another closely related property is *wavelength*: the distance from the peak of one wave to the peak of the next. These two attributes are inversely related. The larger the frequency, the smaller the wavelength – and vice versa



Electromagnetic waves

Definition: Electromagnetic waves or EM waves are waves that are created as a result of vibrations between an electric field and a magnetic field. In other words, EM waves are composed of oscillating magnetic

Description: Electromagnetic waves are formed when an electric field comes in contact with a magnetic field. They are hence known as ‘electromagnetic’ waves. The electric field and magnetic field of an electromagnetic wave are perpendicular (at right angles) to each other. They are also perpendicular to the direction of the EM wave.

EM waves travel with a constant velocity of 3.00 x 108 ms-1 in vacuum. They are deflected neither by the electric field, nor by the magnetic field. However, they are capable of showing interference or diffraction. An electromagnetic wave can travel through anything - be it air, a solid material or vacuum. It does not need a medium to propagate or travel from one place to another. Mechanical waves (like sound waves or water waves), on the other hand, need a medium to travel. EM waves are 'transverse' waves. This means that they are measured by their amplitude (height) and wavelength (distance between the highest/lowest points of two consecutive waves).

The highest point of a wave is known as 'crest', whereas the lowest point is known as 'trough'. Electromagnetic waves can be split into a range of frequencies. This is known as the electromagnetic spectrum. Examples of EM waves are radio waves, microwaves, infrared waves, X-rays, gamma

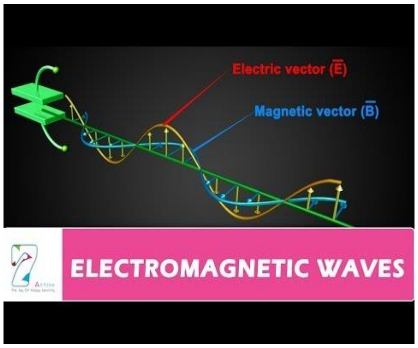
In the late 17th century, scientists were embroiled in a debate about the fundamental nature of light – whether it was a wave or a particle. Sir Issac Newton was a strong advocate of the particle nature of light. But, the Dutch physicist, Christian Huygens believed that light was made up of waves vibrating up and down perpendicular to the direction of the wave propagation, and therefore formulated a way of visualizing wave propagation. This became known as ‘Huygens’ Principle‘.
The wave theory of light proposed by Christian Huygens has stood the test of time and today, it is considered the backbones of optics. Here, in the article, let us discuss the wave theory of light in detail.

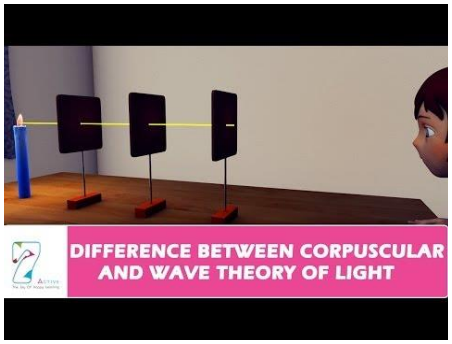
History Of The Wave Theory Of Light

Light always piqued the curiosity of thinkers and scientists. But it wasn’t until the late 17th century that scientists began to comprehend the properties of light. Sir Issac Newton proposed that light was made of tiny particles known as the photons while Christian Huygens believed that light was made of waves propagating perpendicular to the direction of its movement.

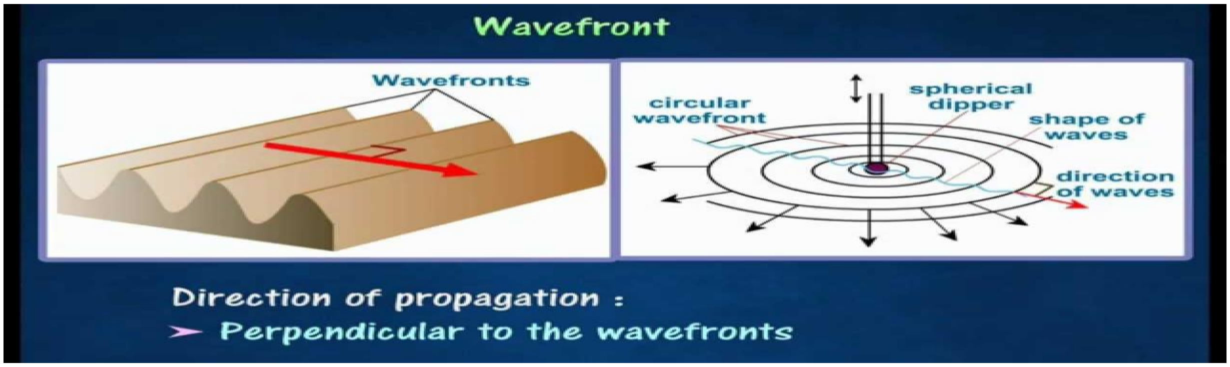
In 1678, Huygen's proposed that every point that a luminous disturbance meets turns into a source of the spherical wave itself. The sum of the secondary waves, which are the result of the disturbance, determines what form the new wave will take. This theory of light is known as the 'Huygens' Principle'.
Using the above-stated principle, Huygen's was successful in deriving the laws of reflection and refraction of light. He was also successful in explaining the linear and spherical propagation of light using this theory. However, he wasn't able to explain the diffraction effects of light. Later, in 1803, the experiment conducted by Thomas Young on the interference of light proved Huygen's wave theory of light to be correct. Later in 1815, Fresnel provided mathematical equations for Young's experiment.
Max Planck proposed that light is made of finite packets of energy known as a light quantum and it depends on the frequency and velocity of light. Later, in 1905, Einstein proposed that light possessed the characteristics of both particle and wave. He suggested that light is made of small particles called photons. Quantum mechanics gave proof of the dual nature of light.

Video Link:

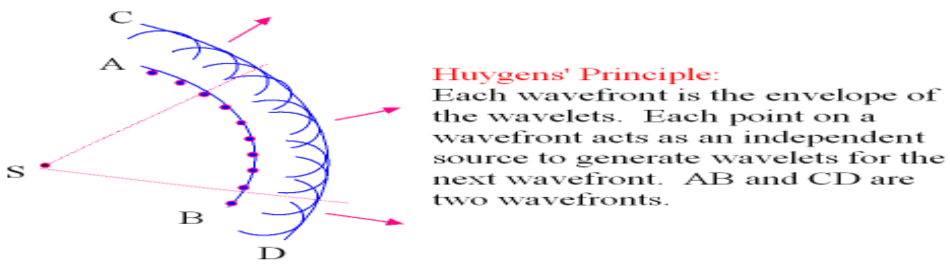





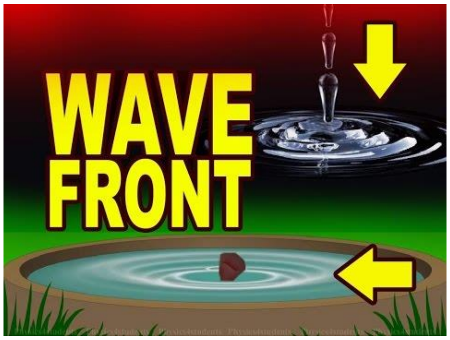
2.Wave front



Wave front, imaginary surface representing corresponding points of a wave that vibrate in unison. When identical waves having a common origin travel through a homogeneous medium, the corresponding crests and troughs at any instant are in phase; *i.e.*, they have completed identical fractions of their cyclic motion, and any surface drawn through all the points of the same phase will constitute a wave front.

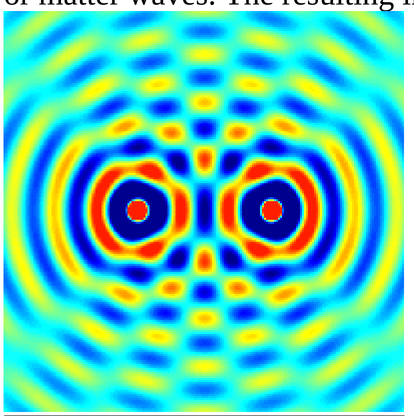


Videos

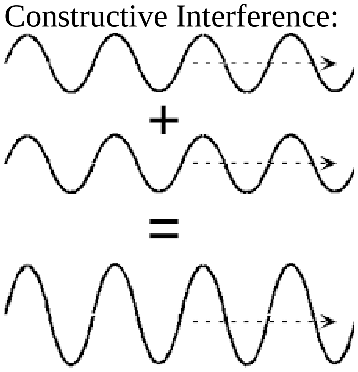


3.Interference

In physics, interference is a phenomenon in which two waves superpose to form a resultant wave of greater, lower, or the same amplitude. Constructive and destructive interference result from the interaction of waves that are correlated or coherent with each other, either because they come from the same source or because they have the same or nearly the same frequency. Interference effects can be observed with all types of waves, for example, light, radio, acoustic, surface water waves, gravity waves, or matter waves. The resulting images or graphs are called interferograms

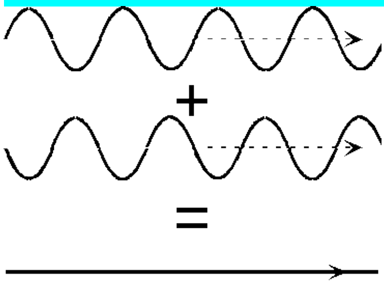


Constructive Interference:



If we add these two waves together, point-by-point, we end up with a new wave that looks pretty much like the original waves but its amplitude is larger. This situation, where the resultant wave is bigger than either of the two original, is called constructive interference. The waves are adding together to form a bigger wave. You may be thinking that this is pretty obvious and natural of course the sum of two waves will be bigger than each wave on its own. However, carefully consider the next situation, again where two waves with the same frequency are traveling in the same direction:

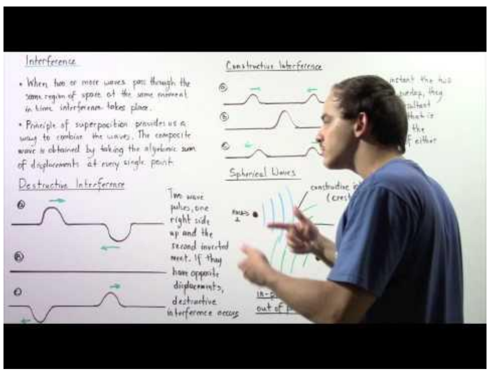
Destructive Interference:



Now what happens if we add these waves together? When the first wave is up, the second wave is down and the two add to zero. When the first wave is down and the second is up, they again add to zero. In fact, at all points the two waves exactly cancel each other out and there is no wave left! This is the single most amazing aspect of waves. The sum of two waves can be less than either wave, alone, and can even be zero. This is called destructive interference.

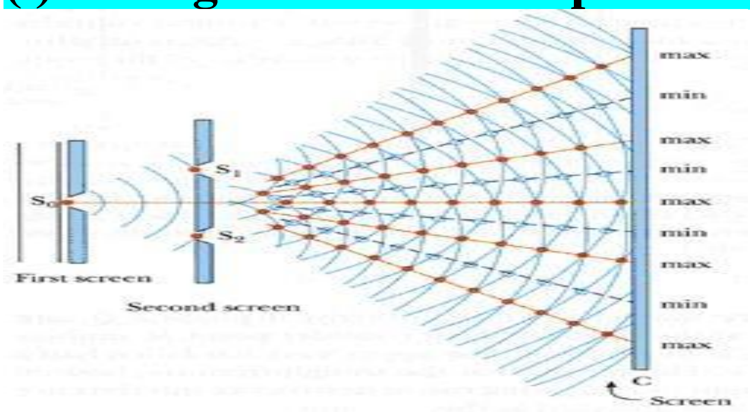
When the peaks of the waves line up, there is constructive interference. Often, this is describe by saying the waves are "in-phase". Although this phrase is not so important for this course, it is so commonly used that I might use it without thinking and you may hear it used in other settings. Similarly, when the peaks of one wave line up with the valleys of the other, the waves are said to be "out-of-phase". Phase, itself, is an important aspect of waves, but we will not use this concept in this course.

Videos



https://www.britannica.com/science/interference-physics

(i) Young’s double slit experiment



The first practical demonstration of optical interference was provided by THOMAS YOUNG in 1801. His experiment gave a very strong support to the wave theory of light.

EXPERIMENTAL ARRANGEMENT

'S' is a slit, which receives light from a source of monochromatic light. As 'S' is a narrow slit so it diffracts the light and it falls on slits A and B. After passing through the two slits, interference between two waves takes place on the screen. The slits A and B act as two coherent sources of light. Due to interference of waves alternate bright and dark fringes are obtained on the screen.

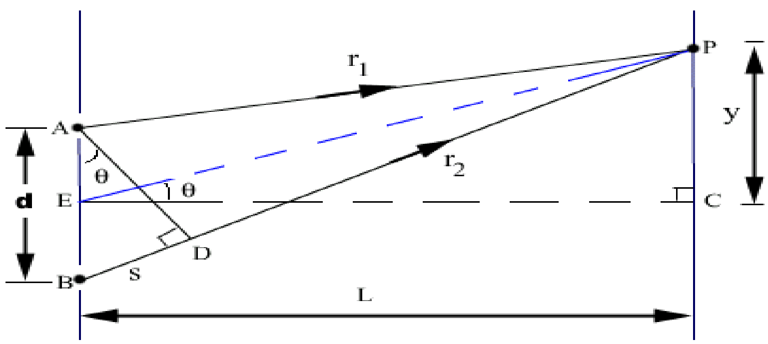
QUANTITATIVE ANALYSIS

Let the wave length of light = l

Distance between slits A and B = d

Distance between slits and screen = L

Consider a point 'P' on the screen where the light waves coming from slits A and B interfere such that PC=y. The wave coming from A covers a distance AP=r1 and the wave coming from B covers a distance BP=r2 such that PB is greater than PA.



Path difference = BP-AP = BD

S = r2-r1 = BD

Sinθ = BD/AB

Or

sinθ = s/d

Or

S = dsinθ --------(1)

Since the value of 'd' is very very small as compared to L, therefore, θ will also be very small. In this condition we can assume that :

Sinθ = tanθ

From (1)

S = dtanθ ---(2)

In right angled DPEC

Tanθ = PC/EC = y/L

Putting the value of tanθ in eq. (2), w get

S = dy/L

Or

$$y = SL/d \text{ -----(3)}$$

FOR BRIGHT FRINGE

For bright fringe $S = m\lambda$ -----(3)

Therefore, the position of bright fringe is:

$$y = m\lambda L/d$$

FOR DARK FRINGE AT P

For destructive interference, path difference between two waves is $(m+1/2)\lambda$ ----(3)

Therefore, the position of dark fringe is:

$y = (m+1/2)\lambda L/d$

FRINGE SPACING

The distance between any two consecutive bright fringes or two consecutive dark fringes is called fringe spacing. Fringe spacing or thickness of a dark fringe or a bright fringe is equal. It is denoted by Δx.

Consider bright fringe.

$$y = m\lambda L/d$$

For bright fringe m=1

$$y1 = (1)\lambda L/d$$

for next order bright fringe m=2

$$y2 = (2)\lambda L/d$$

fringe spacing = y2 - y1

or

$$\Delta x = (2)\lambda L/d - (1)\lambda L/d$$

$$\Delta x = \lambda L/d\ (2-1)$$

$$\Delta x = \lambda L/d$$

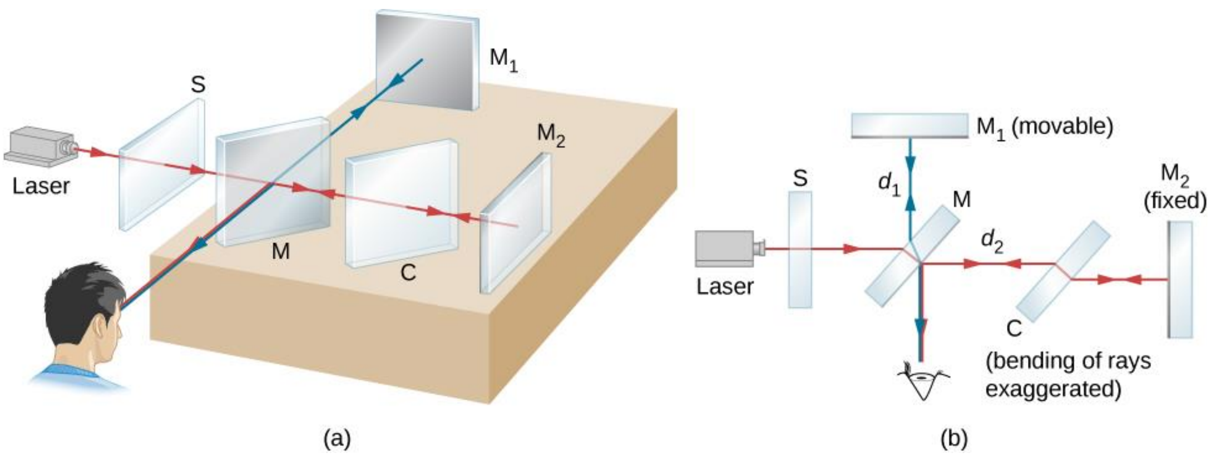
Similar result can be obtained for dark fringe.

(ii) Michelson 's Interferometer

The Michelson interferometer (invented by the American physicist Albert A. Michelson, 1852–1931) is a precision instrument that produces interference fringes by splitting a light beam into two parts and then recombining them after they have traveled different optical paths. depicts the interferometer and the path of a light beam from a single point on the extended source S, which is a ground-glass plate that diffuses the light from a monochromatic lamp of wavelength . The beam strikes the half-silvered mirror M, where half of it is reflected to the side and half passes through the mirror. The reflected light travels to the movable plane mirror , where it is reflected back through M to the observer. The transmitted half of the original beam is reflected back by the stationary mirror and then toward the observer by M.

(a) The Michelson interferometer. The extended light source is a ground-glass plate that diffuses the light from a laser.

(b) A planar view of the interferometer.

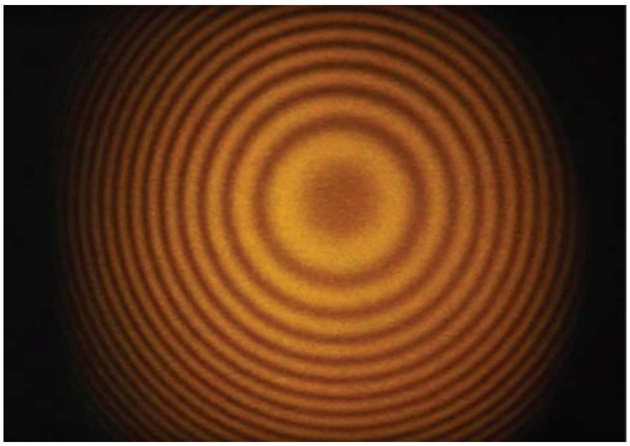


Because both beams originate from the same point on the source, they are coherent and therefore interfere. Notice from the figure that one beam passes through M three times and the other only once. To ensure that both beams traverse the same thickness of glass, a compensator plate C of transparent glass is placed in the arm containing .

This plate is a duplicate of M (without the silvering) and is usually cut from the same piece of glass used to produce M. With the compensator in place, any phase difference between the two beams is due solely to the difference in the distances they travel.

The path difference of the two beams when they recombine is , where is the distance between M and , and is the distance between M and . Suppose this path difference is an integer number of wavelengths . Then, constructive interference occurs and a bright image of the point on the source is seen at the observer. Now the light from any other point on the source whose two beams have this same path difference also undergoes constructive interference and produces a bright image. The collection of these point images is a bright fringe corresponding to a path difference of When is moved a distance , this path difference changes by , and each fringe moves to the position previously occupied by an adjacent fringe. Consequently, by counting the number of fringes *m* passing a given point as is moved, an observer can measure minute displacements that are accurate to a fraction of a wavelength, as shown by the relation

$$d = m\frac{\lambda_0}{2}.$$



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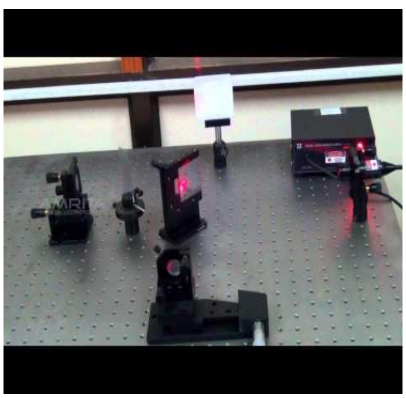
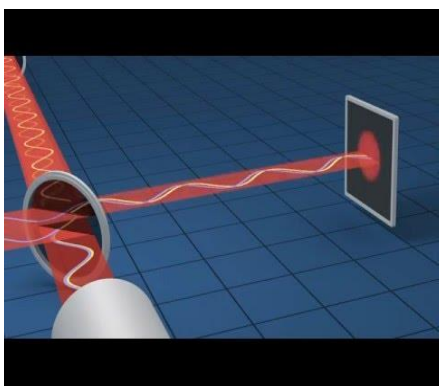
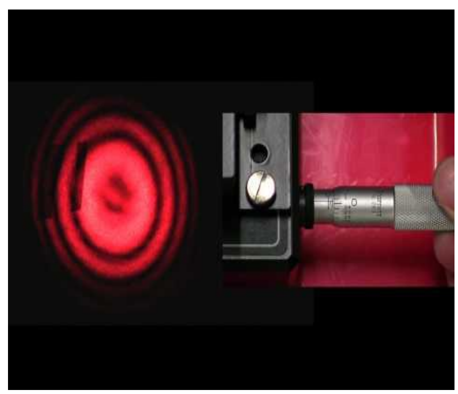




4.Diffraction

The spreading of waves around obstacles. Diffraction takes place with sound; with electromagnetic radiation, such as light, X-rays, and gamma rays; and with very small moving particles such as atoms, neutrons, and electrons, which show wavelike properties. One consequence of diffraction is that sharp shadows are not produced. The phenomenon is the result of interference (i.e., when waves are superimposed, they may reinforce or cancel each other out) and is most pronounced when the wavelength of the radiation is comparable to the linear dimensions of the obstacle. When sound of various wavelengths or frequencies is emitted from a loudspeaker, the loudspeaker itself acts as an obstacle and casts a shadow to its rear so that only the longer bass notes are diffracted there. When a beam of light falls on the edge of an object, it will not continue in a straight line but will be slightly bent by the contact, causing a blur at the edge of the shadow of the object; the amount of bending will be proportional to the wavelength. When a stream of fast particles impinges on the atoms of a crystal, their paths are bent into a regular pattern, which can be recorded by directing the diffracted beam onto a photographic film.

"The bending and spreading of light waves around sharp edges or corner or through small openings is called Diffraction of Light"

CONDITIONS FOR DIFFRACTION

Diffraction effect depends upon the size of obstacle. Diffraction of light takes place if the size of obstacle is comparable to the wavelength of light.

Light waves are very small in wavelength, i.e. from 4 x 10-7 m to 7 x 10-7 m. If the size of opening or obstacle is near to this limit, only then we can observe the phenomenon of diffraction.

TYPES OF DIFFRACTION

Diffraction of light can be divided into two classes:

- Fraunhoffer diffraction.
- Fresnel diffraction.

FRAUNHOFFER DIFFRACTION

In Fraunhoffer diffraction,

- Source and the screen are far away from each other.
- Incident wave fronts on the diffracting obstacle are plane.
- Diffracting obstacle give rise to wave fronts which are also plane.
- Plane diffracting wave fronts are converged by means of a convex lens to produce diffraction pattern.

FRESNEL DIFFRACTION

In Fresnel diffraction,

- Source and screen are not far away from each other.
- Incident wave fronts are spherical.
- Wave fronts leaving the obstacles are also spherical.
- Convex lens is not needed to converge the spherical wave fronts.

DIFFRACTION GRATING

A diffraction grating is an optical device consists of a glass or polished metal surface over which thousands of fine, equidistant, closely spaced parallel lines are been ruled.

PRINCIPLE

Its working principle is based on the phenomenon of diffraction. The space between lines act as slits and these slits diffract the light waves there by producing a large number of beams which interfere in such away to produce spectra.

GRATING ELEMENT

Distance between two consecutive slits(lines) of a grating is called grating element. If 'a' is the separation between two slits and 'b' is the width of a slit, then grating element 'd' is given by;

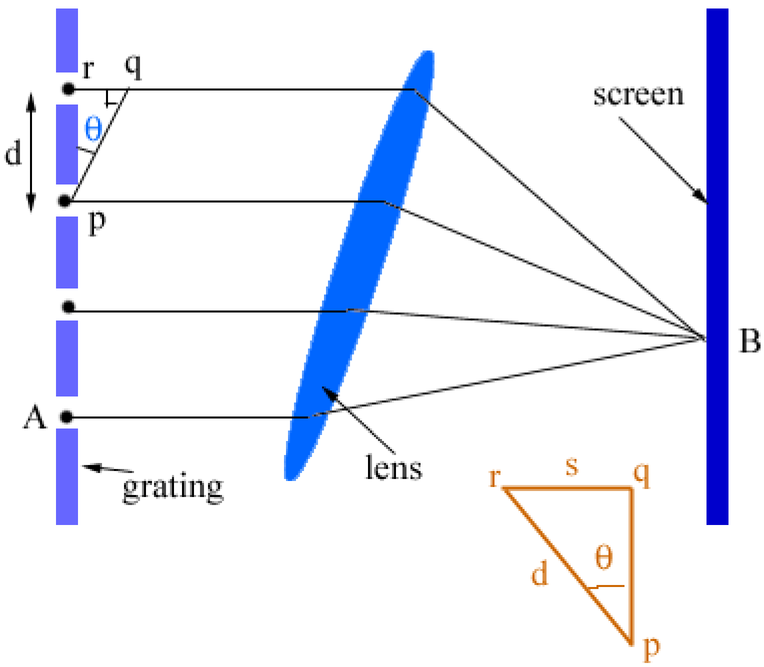
$d = a + b$

OR

d = length of grating/no. of lines

DETERMINATION OF WAVE LENGTH OF LIGHT BY DIFFRACTION GRATING

Consider two parallel rays of light r1 and r2 falling on a grating .After passing through slits they are diffracted and brought to focus on a screen at point B by using a convex lens.. Draw a perpendicular 'pq' from P on r1. Ray (1) covers a distance "r q" more than ray (2).



Now consider right angled **Δrpq**

rq/rp = sinθ

Or rq= rp sinθ

But rp = (a+b)

(a+ b) = d (grating element)

rq = dsinθ -----(1)

Where rq= path difference of r1 and r2.

We know that for constructive interference at point 'B', path difference between r1 and r2 will be 0, l, 2l, 3ll, …….,mll.

Therefore, rq = ml for bright point

Putting this value in equation (1), we get

ml = dsinq where m = order

This equation is called "grating equation" and is used to determine he wavelength of light.

CONCLUSION

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'm' is called the order of grating and it is the number of bright or dark fringe obtained on the screen.

For m=0 , q=0, central bright maxima of zeroth order.

m=1 , q=q1, 1st order bright maxima (path difference = l)

m=2 , q=q2, 2nd order bright maxima (path difference = 2l)

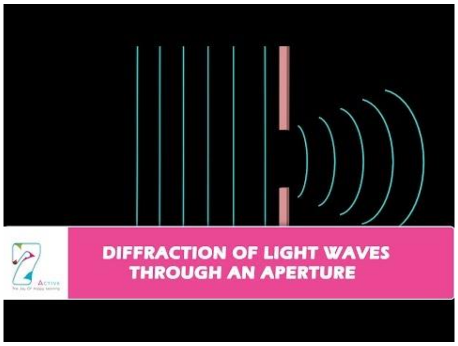
With the increase in 'm', fringes of decreasing width and less brightness are obtained.

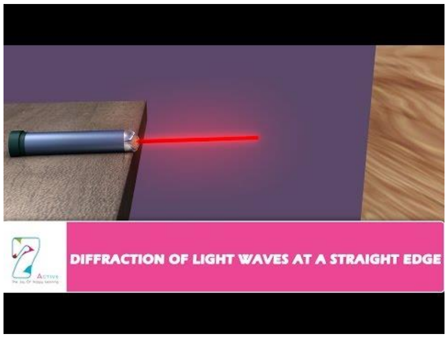
No order of line is possible at q>90°.

CHARACTERISTICS OF
GRATING SPECTRA

- Spectra of different orders are obtained symmetrically on both sides of zeroth order image.
- Spectral lines are almost straight and quite sharp.
- Spectral colors are in the order
- The spectral lines are more and more dispersed as we go to higher orders.
- Most of the incident intensity goes to zero th order and rest of it is distributed among the other orders.

Videos:





5.Polarization

Natural sunlight and almost every other form of artificial illumination transmits light waves whose electric field vectors vibrate in all perpendicular planes with respect to the direction of propagation. When the electric field vectors are restricted to a single plane by filtration, then the light is said to be polarized with respect to the direction of propagation and all waves vibrate in the same plane.

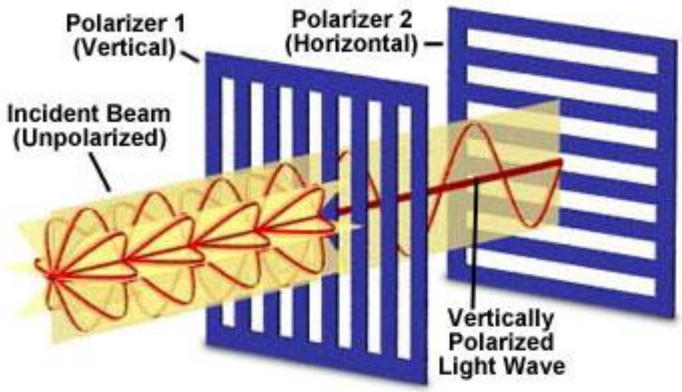


Figure 1

This concept is illustrated in Figure 1 below, and we have also constructed an interactive Java tutorial that explores the interaction of light waves with polarizers. In this example, the incident light electric field vectors are vibrating perpendicular to the direction of propagation in an equal distribution of all planes before encountering the first polarizer. The polarizers illustrated above are actually filters containing long-chain polymer molecules that are oriented in a single direction. Only the incident light that is vibrating in the same plane as the oriented polymer molecules is absorbed, while light vibrating at right angles to the plane is passed through the first polarizing filter. In Figure 1, polarizer 1 is oriented vertically to the incident beam so it will pass only the waves that are vertical in the incident beam. The wave passing through polarizer 1 is subsequently blocked by polarizer 2 because the second polarizer is oriented horizontally with respect to the electric field vector in the light wave. The concept of using two polarizers oriented at right angles with respect to each other is commonly termed crossed polarization and is fundamental to the practice ofpolarized light microscopy.

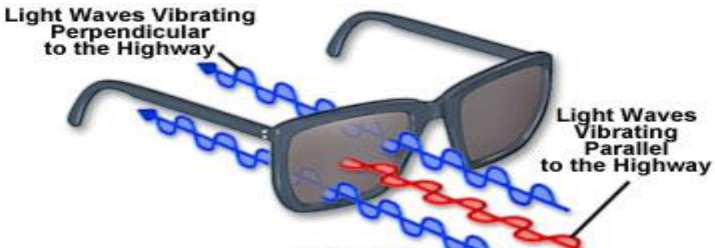


Figure 2

An excellent example of the basic application of liquid crystals to display devices can be found in the seven-segment LCD numerical display (Figure 3). Here, the liquid crystalline phase is sandwiched between two glass plates that have electrodes attached similar to those depicted in the illustration below. In figure 3, the glass plates are drawn with seven black electrodes that can be individually charged (these electrodes are transparent to light in real devices). Light passing through polarizer 1 is polarized in the vertical direction and, when no current is applied to the electrodes, the liquid crystalline phase induces a 90 degree "twist" of the light and it can pass through polarizer 2, which is polarized horizontally and is perpendicular to polarizer 1. This light can then form one of the seven segments on the display.

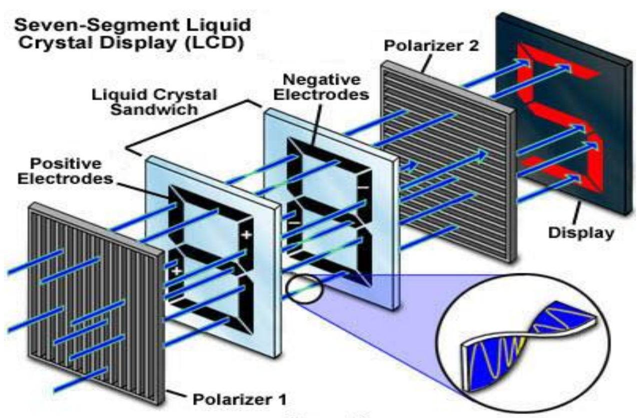
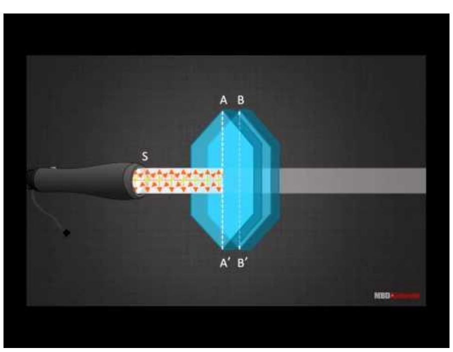
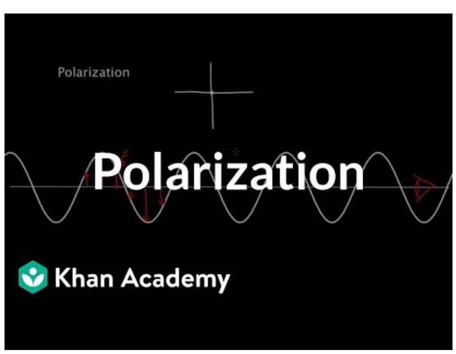


Figure 3

Videos





Learning outcomes

The students will:

• describe light waves as a part of electromagnetic waves spectrum.
• describe the concept of wave front.
• state Huygens's principle and use it to construct wave front after a time interval.
• state the necessary conditions to observe interference of light.
• describe Young's double slit experiment and the evidence it provides to support the wave theory of light.
• explain color pattern due to interference in thin films.
• describe the parts and working of Michelson Interferometer and its uses.
• explain diffraction and identify that interference occurs between waves that have been diffracted.
• describe that diffraction of light is evidence that light behaves like waves.
• describe and explain diffraction at a narrow slit.
• describe the use of a diffraction grating to determine the wavelength of light and carry out calculations using $d \sin \theta = n \lambda$.
• describe the phenomena of diffraction of X-rays through crystals.
• explain polarization as a phenomenon associated with transverse waves.
• identify and express that polarization is produced by a Polaroid.
• explain the effect of rotation of Polaroid on Polarization.
• explain how plane polarized light is produced and detected.

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