Glossary

Abbreviated action | Abbreviated action is defined to be

$$S_0 \equiv \int_{t_i}^{t_f} \sum_j^n p_j \dot{q}_j dt = \int_{t_i}^{t_f} (L + H) dt = \int_{t_i}^{t_f} 2T dt = \int_{t_i}^{t_f} \mathbf{p} \cdot \delta \mathbf{q}.$$

This was anticipated by Leibniz in 1687 and subsequently proposed by Maupertuis in 1744. It was an early statement of Hamilton's Stationary Action Principle.

Action-angle variables | A transformation to action-angle variables is convenient for systems involving periodic motion such as periodic oscillations or closed trajectories in phase space. The action-phase integral is especially useful for trajectories involving periodic motion such as celestial orbits.

Adiabatic invariance | Finding constants for time-dependent Hamiltonians is difficult. However, for adiabatic motion the time dependence often can be sufficiently slow to be ignored.

Apocenter | The furthest point for an orbiting body from the center of attraction

Apsis | Denotes either of the extreme points in the orbit of a planetary body about it's primary body. The prefix for the shortest separation distance is peri and apo for the longest separation.

Asymmetric rotor | A quadrupole-deformed body for which the quadrupole deformation along the three orthogonal axes are different. That is, it is a triaxially-deformed quadrupole top.

Attractor | After many closed cycles in phase space, non-linear oscillatory systems can converge to either a point attractor or a limit cycle attractor.

Autonomous system | Independent, self-governing, system subject to it's own laws and schedule.

Barycenter | In astronomy the barycenter is the center of mass of two or more bodies that orbit one another.

Bernoulli | Pioneered development of the calculus of variations including solving the theory of the catenary, the brachistochrone, and Fermat's Principle.

Bertrand's theorem | Showed that the inverse square law and linear harmonic oscillator are the only radial dependences of the two-body problem that lead to stable closed orbits.

Bifurcation diagram | Simplifies the presentation of the dynamical motion of a periodic system by sampling the location once per orbit period.

Black hole | A region of space where the gravitational field is so intense that neither matter nor radiation can escape.

Bohr | Neils Bohr was a Danish Nobel Prize winner in Physics who pioneered the old quantum theory, the correspondence principle, the early model of the atom, nuclear fission, and nuclear fusion

Bohr-Sommerfeld atom | The first viable model of the hydrogen atom that was based on classical mechanics.

Brachistochrone | The path between two points for which a body moves under gravity in the shortest possible time. The mathematics was solved by Bernoulli and Euler.

Brahe | Tycho Brahe was a Danish nobleman known for his accurate and comprehensive astronomical observations.

Bulk modulus | The bulk modulus is a measure of the resistance to compression of a substance.

Buoyancy forces | Is the upward force exerted by a fluid that opposes the weight of a partially or fully immersed object.

Canonical coordinates | In classical mechanics the canonical coordinates are q^{i} and p_{i} in phase space. The canonical coordinates satisfy the fundamental Poisson bracket relations \{q^{i},q^{j}\}=0\qquad \qquad \{p_{i},p_{j}\}=0\qquad \qquad \{q^{i},p_{j}\}=\delta_{ij} \nonumber

Canonical equations of motion | Jacobi's name for Hamilton's fundamental equations of motion and the corresponding set of conjugate variables.

Canonical perturbation theory | Closed form solutions of dynamical systems are rarely available. However, some systems can be solved by the addition of a small perturbation to a solvable problem.

Canonical transformation | In Hamiltonian mechanics a canonical transformation is a change of the canonical coordinates that preserves the form of Hamiltonian mechanics.

Cartesian coordinates | A cartesian coordinate system in a plane is one that is defined by a pair of numerical coordinates.

Catenary | The shape assumed by an idealized uniform chain that is hanging from both ends.

Cayley | Arthur Cayley was a prolific British mathematician who developed the concept of matrix algebra in 1855.

Center of mass | The center of mass of a distribution of mass is a unique point where applied forces do not lead to rotational torques.

Center of momentum | The center of momentum frame is defined as the inertial frame for which the sum of the linear momenta of all parts of the body is zero.

Center of percussion | The center of percussion of an extended body is the location where a perpendicular impact will produce no reactive shock on the pivot point.

Centrifugal force | The centrifugal force that a body exhibits in a rotating frame is due to the inertia of that the body moving in a straight line in the non-rotating inertial frame.

Chaos | Random and unpredictable motion of a body.

Characteristic function | If the Hamiltonian does not depend explicitly on time, then the Hamilton-Jacobi equation separates into \mathbf{S(q,\alpha ,}t\mathbf{)=W(q,\alpha)-E(\alpha)}t \nonumber where \mathbf{W(q,\alpha)} is Hamilton's characteristic function for a time-independent Hamiltonian.

Chasles' theorem | A rotation about any axis is equivalent to a rotation through the same angle about any axis parallel to it, together with a simple translation in a direction perpendicular to the axis.

Collective synchronization | Collective synchronization of many weakly-coupled oscillators is discussed in the Kuramoto model.

Commutation relation | The commutator of two elements of a ring is defined as [a,b]=ab-ba

Commute | In mathematics a binary operation is commutative if changing the order of the operands does not change the result.

Conjugate momentum | The conjugate momentum associated with coordinate q_{j} is defined to be \frac{\partial L}{\partial \dot{q}_{j}} \equiv p_{j}

Conservation of angular momentum | When the torque around an axis is zero then the angular momentum about that axis is a constant of motion.

Conservation of linear momentum | The linear momentum in a given direction is conserved if no forces act in that same direction

Conservative forces | A conservative force is a force for which the total work done moving a mass between two points is independent of the path taken.

Constrained motion | Constrained motion occurs when an object is forced to move in a restricted way.

Constraint forces | Constraint forces are the forces applied to constrain the motion of a body.

Constraints geodesic | The constraint forces applied to force a body to follow a certain trajectory.

Constraints geometric | Constraints applied to ensure that a body follows a specified trajectory.

Constraints holonomic | Holonomic constrained motion involves constraint forces that restrict the motion according to algebraic relations that couple the holonomic generalized coordinates.

Constraints isoperimetric | Isoperimetric constraints often involve optimization of a functional under an integral constraints, such as the Queen Dido problem, example 5.9.

Constraints kinematic | Kinematic constraints are constraints that restrict motion of rigid bodies that decreases the number of active degrees of freedom.

Constraints nonholonomic | The nonholonomic generalized coordinates are not coupled by algebraic relations.

Constraints partial holonomic | One-sided constraints involve examples such as partial-holonomic systems where the active regime of the constraint force applies only in one direction.

Constraints rheonomic | Rheonomic constraints are explicitly time-dependent constraints.

Constraints scleronomic | Equations of constraint that do not contain the time as an explicit variable.

Continuity equation | A continuity equation is an equation that relates conserved quantities, such as fluid volume, that is being transported in fluid flow.

Contravariant tensor | Covariance and contravariance of physical entities change with change of basis. For example a change of scale from meters to centimeters of the basis divides the reference axes by 100. Then the measured velocity vectors need to be multiplied by 100. Vectors that change scale inversely to changes of scale are called contravariant. By contrast the gradient has units that are the inverse of the distance and the components of these covectors change in the same way as changes in scale and are called covectors.

Coordinate systems; cartesian | Cartesian coordinates in a plane specifies each location uniquely by a pair of numerical coordinates which are the distances to the point from two perpendicular axes.

Coordinate systems; curvilinear | In geometry curvilinear coordinates correspond to a coordinate system in Euclidean space where the coordinate lines may be curved.

Coordinate systems; polar | In mathematics the polar coordinate system is a two-dimensional coordinate system for which each point on a plane is determined by a distance from a reference point and an angle from the reference direction.

Coordinate systems; spherical | In mathematics a spherical coordinate system is a coordinate system for three-dimensional space where the location of the point is specified by three numbers; the radial distance of the point from a fixed origin r; the polar angle measured from a fixed zenith \theta , and the azimuthal angle \phi .

Coordinate transformations | A unitary rotation accomplished by a rotation matrix acting upon the coordinates.

Copernicus | Nicolaus Copernicus (1473-1543) formulated a model of the universe that placed the Sun, rather than the Earth, at the center of the universe

Correspondence principle | The correspondence principle states that the behavior of systems that are described by quantum theory, must reproduce classical physics in the limit of large quantum numbers.

Coulomb excitation | Electromagnetic excitation of the nucleus by the atomic electromagnetic fields during an atomic collision.

Coupled oscillator | N-body coupled oscillator systems normally have N independent oscillatory modes involving complicated coordinated motion of the N bodies, with each mode having different characteristic frequencies.

Covariant tensor | Covariance, and contravariance, of physical entities change with change of basis. For example a change of scale from meters to centimeters of the basis divides the reference axes by 100. Then the measured velocity vectors need to be multiplied by 100. Such vectors change scale inversely to changes of scale, and are called contravariant. By contrast the gradient has units that are the inverse of the distance and the components of these covectors, change in the same way as changes in scale and are called covectors.

Cut-off frequency | The maximum or minimum frequency of an oscillatory system.

Cyclic coordinates | A cyclic coordinate is one that does not explicitly appears in the Lagrangian. For example, the momentum p_{k} is a constant of motion if the conjugate coordinate q_{k} is cyclic, which is Noether's theorem

Cyclic Routhian | The cyclic routhian behaves like a Hamiltonian for the ignorable cyclic coordinates \mathbf{\omega } and \mathbf{J}, while it behaves like a negative Lagrangian for all other coordinates.

d'Alembert's Principle | d'Alembert's Principle of virtual work states that a system of rigid bodies is in dynamic equilibrium when the virtual work of the sum of the applied forces, plus the inertial forces, is zero. This extends the Principle of Virtual work to dynamical systems.

de Broglie matter wave | In 1924 Louis de Broglie's hypothesized that matter and energy should be symmetrical implying that moving matter should display wave-like properties.

Delta-function analysis | The Dirac delta function (\delta-function) is a generalized function introduced by Paul Dirac. The delta function is used to model an idealized point mass or charge that is zero except at zero where the function has an integral of unity. That is it symbolizes a unit impulse.

Differential orbit equation | The differential orbit equation relates the shape of the orbital motion, in plane polar coordinates, to the radial dependence for the two-body central force. A Binet coordinate transformation can simplify the differential orbit equation.

Dirac | Paul Dirac, a 23-year old graduate student showed that the Poisson bracket representation of Hamiltonian mechanics is consistent with the Heisenberg equation representation of quantum mechanics. He developed a relativistic theory of quantum mechanics and predicted antiparticles.

Discrete lattice chain | Crystalline lattices and linear molecules are important examples of discrete lattice chains that primarily involve nearest neighbor interactions.

Driven damped oscillator | The driven linearly-damped linear oscillator provides the foundation for lattice chains and molecular binding.

Eccentricity vector | The two-body central interaction leads to two invariant first-order integrals, namely the conservation of energy and the conservation of angular momentum. For the special case of the inverse-square law, there is a third invariance which Hamilton called the eccentricity vector which unambiguously defines the orientation and direction of the major axis of the elliptical orbit..

Einstein | Albert Einstein (1879 - 1955), and Isaac Newton are widely recognized as being among the greatest physicists. Einstein developed both the Special Theory of Relativity and the General Theory of Relativity, both of which are of fundamental importance in physics.

Einstein's general theory of relativity | Einstein's General theory of Relativity, published in 1915, is the geometric theory of gravitation. It correctly predicted the existence of black holes, gravitational waves.

Einstein's special theory of relativity | Einstein's Special theory of Relativity, published in 1905, states that (1) the laws of physics are invariant in all inertial frames of reference, and (2) The speed of light in vacuum is the same a constant of nature.

Elasticity | The degree of stretching or compression of materials subject to tension or compression.

Euler | Leonhard Euler (1707 - 1783) was a brilliant mathematican who made many remarkable contributions to mathematics. He pioneered many aspects of analytical mechanics.

Euler angles | The three Euler angles (\phi ,\theta ,\psi) specify the rotation angle \phi about the space-fixed axis, \theta about the line of nodes, and \psi about the body-fixed 3 axis. These three angles are required to rotate from the laboratory frame of reference to the body-fixed frame of reference.

Euler's equations for rigid-body rotation | The Euler equations of motion for a rigid-body is the force field expressed in the body-fixed coordinate frame assuming applied external torques N_{1},N_{2}, and N_{3} acting about the three axes. \begin{eqnarray*} I_{1}\dot{\omega}_{1}-\left(I_{2}-I_{3}\right) \omega _{2}\omega _{3} &=&N_{1} \\ I_{2}\dot{\omega}_{2}-\left(I_{3}-I_{1}\right) \omega _{3}\omega _{1} &=&N_{2} \\ I_{3}\dot{\omega}_{3}-\left(I_{1}-I_{2}\right) \omega _{1}\omega _{2} &=&N_{3} \end{eqnarray*}

Euler's hydrodynamic equation | \frac{\partial \mathbf{v}}{\partial t}+\left(\mathbf{v\cdot \nabla }\right) \mathbf{v=-}\frac{1}{\rho }\mathbf{\nabla }\left(P+\rho V\right) \nonumber

Euler-Lagrange equation | \left\{ \frac{d}{dt}\left(\frac{\partial L}{\partial \dot{q}_{j}}\right) - \frac{\partial L}{\partial q_{j}}\right\} =Q_{j} \nonumber assuming that the n generalized forces Q_{j} for the n generalized coordinates are independent, and where n\geq j\geq 1.

Euler-Lagrange equation | A second-order partial differential equation whose solutions are the functions for which a given functional is stationary.

Fermat's principle | The transit time \tau of a light beam between two locations A and B, in a medium with position-dependent refractive index n(s), is given by \tau =\int_{t_{A}}^{t_{B}}dt=\frac{1}{c}\int_{A}^{B}n(s)ds \nonumber Fermat's Principle predicts Snell's Law for refraction at an interface.

Fluid dynamics | The laminar and turbulent flow of liquids and gases is the subject of fluid dynamics.

Four vector | An object comprising four orthogonal components, such as three spatial components plus time, used in Special Relativity.

Fourier analysis | Decomposition or synthesis of the oscillatory components of a function.

Galilean invariance | The laws of motion are the same in all inertial frames.

Gauge invariance | The standard Lagrangian is indefinite with respect to 1) addition of a constant to the scalar potential, 2) addition of a constant kinetic energy, and 3) addition of a differentiable function \Lambda (q_{i},t) that has continuous second derivatives.

General theory of relativity | Einstein's General theory of Relativity, published in 1915, is the geometric theory of gravitation. It correctly predicted the existence of black holes, gravitational waves.

Generalized energy theorem | \begin{equation} \frac{dH\left(\mathbf{q,p,}t\right) }{dt}=\frac{dh(\mathbf{q},\mathbf{\dot{q }},t)}{dt}=\sum_{j}\dot{q}_{j}\left[Q_{j}^{EXC}+\sum_{k=1}^{m}\lambda _{k} \frac{\partial g_{k}}{\partial q_{j}} (\mathbf{q},t)\right] -\frac{\partial L(\mathbf{q},\mathbf{\dot{q}},t)}{\partial t} \end{equation} The Hamiltonian H\left(\mathbf{q,p,}t\right), and generalized energy h(\mathbf{q},\mathbf{\dot{q}},t), both are constants of motion if the Lagrangian is a constant of motion, and if the external non-potential forces are zero. This is an example of Noether's theorem, where the symmetry of time independence leads to conservation of the conjugate variable, which in this case is the Hamiltonian or Generalized energy.

Geodesic | The shortest possible line between two points on a curved surface.

Gravitational mass | The constant of proportionality of the force experienced by matter in a gravitational field

Gravitational wave | Disturbances in the curvature of space-time generated by accelerations.

Hamilton's Principle Function | The modern term "action functional" was called "Hamilton's Principle Function" in older text books.

Hamilton's stationary-action principle | Hamilton's Stationary Action Principle states that the action functional is stationary with respect to change of the variables, i.e. \delta S=\delta \int_{t_{i}}^{t_{f}}L (\mathbf{q, \dot{q}}, t) dt=0. \nonumber

Hamilton-Jacobi equation | A formulation of mechanics that allows the motion of a particle to be represented by a wave.

Hamiltonian mechanics | Hamiltonian mechanics describes the evolution of conservative physical systems in terms of the Hamiltonian function, which equals the total energy expressed in terms of position and momentum

Heisenberg's Uncertainty Principle | This principle states that the position \Delta x and corresponding momentum \Delta p_{x} cannot be measured simultaneously with arbitrary high precision. That is, \Delta x\Delta p_{x}\geq \frac{\hslash }{2}.

Hodograph | A diagram that gives a pictorial representation of the movement of a body or fluid. It uses the locus of one end of a variable vector, with the other end fixed. This was developed by Hamilton.

Holonomic constraints | Holonomic constrained motion involves constraint forces that restrict the motion according to algebraic relations that couple the generalized coordinates.

Inertia tensor | The inertia tensor can be represented by 3x3 square matrix which defines the rotational properties of body. The individual components of the I_{ij} matrix element are given by I_{ij}\equiv \sum_{\alpha }^{N}m_{\alpha }\left[\delta _{ij}\left(\sum_{k}^{3}x_{\alpha ,k}^{2}\right) -x_{\alpha ,i}x_{\alpha ,j}\right] \nonumber

Inertial frame | An inertial frame is a frame of reference that is not undergoing acceleration. In an inertial frame, a body with zero forces acting moves at constant velocity.

Inertial mass | The constant of proportionality of the acceleration to the force applied to a body.

Jacobian | The Jacobian determinant is defined as being the ratio of the n-dimensional volume element dx_{1}dx_{2}...dx_{n} in one coordinate system, to the volume element dy_{1} dy_{2} ...d y_{n} in the second coordinate system. That is \begin{equation} J(y_{1}y_{2}...y_{n})\equiv \frac{\partial x_{1}\partial x_{2}...\partial x_{n}}{\partial y_{1}\partial y_{2}...\partial y_{n}}=\left\vert \begin{array}{cccc} \frac{\partial x_{1}}{\partial y_{1}} & \frac{\partial x_{1}}{\partial y_{2}} & ... & \frac{\partial x_{1}}{\partial y_{n}} \\ \frac{\partial x_{2}}{\partial y_{1}} & \frac{\partial x_{2}}{\partial y_{2}} & ... & \frac{\partial x_{2}}{\partial y_{n}} \\ \vdots & \vdots & \vdots & \vdots \\ \frac{\partial x_{n}}{\partial y_{1}} & \frac{\partial x_{n}}{\partial y_{2}} & ... & \frac{\partial x_{n}}{\partial y_{n}} \end{array} \right\vert \end{equation}

Lagrange | Joseph Louis Lagrange (1736-1813) was an Italian mathematician who was a student of Leonhard Euler and his work paralleled that of Euler. In 1788 Lagrange published his monumental treatise on analytical mechanics entitled "Mécanique analytique" which describes his new, immensely powerful, analytical technique that can solve any mechanical problem without resorting to geometrical considerations.

Lagrange multipliers | The n Lagrange equations, plus the m equations of constraint, can be used to explicitly determine the n generalized coordinates plus the m constraint forces. That is, n+m unknowns are determined. This Lagrange-multiplier approach is discussed in chapter 5.9.

Lagrangian mechanics | An algebraic method to derive the trajectory of a system by solution of the Euler- Lagrange equations.The Lagrangian is expressed in terms of position and velocity.

Lame' moduli | Lame's two moduli of elasticity (\lambda, \mu) are material dependent.

Legendre transform | Converts functions of one quantity; such as position, into functions of the conjugate quantity such as momentum. Commonly used to relate the Hamiltonian formalism and the Lagrangian formalism.

Leibniz | Gottfried Wilhelm Leibniz (1646-1716) was a contemporary of Newton. He independently developed differential and integral calculus as well as introductory elements of algebraic mechanics

Levi-Civita permutation symbol | In three dimensions \varepsilon _{ijk}=+1 if (i,j,k) is cyclic, \varepsilon _{ijk}=-1 if (i,j,k) is anticyclic, and \varepsilon _{ijk}=0 if two indices are identical.

Liouville's theorem | Describes the conservation of the density in phase-space distribution function, which is constant along trajectories.

Lissajous figure | The Lissajous figure, first discovered by Bowditch, graphically shows the trajectory for complex harmonic motion.

Lorentz force | The Lorentz force predicts the electromagnetic force acting on a moving point charge q in electric and magnetic fields.

Lorentz relativistic transformation | The Lorentz linear transformation, in Minkowski space, provides a mathematical representation of spacetime in Special Relativity.

Lyapunov exponent | A quantitative measure of the instability of a trajectory relative to nearby trajectories.

Mach's principle | Einstein assigned this conjecture to Mach that describes how rotating objects maintain an absolute rotating reference frame.

Matrix diagonalization | An nxn matrix can be transformed to a diagonal form if it has n distinct eigenvalues.

Matrix Hermitian | A square matrix is Hermitian if, and only if, it is self-adjoint

Matrix identity | An identity matrix, for an order n square matrix, is a diagonal matrix with ones on the main diagonal.

Maupertuis | The Principle of Least Action (1744) usually is attributed to Pierre Louis Maupertuis who summized that nature is thrifty in all its action. He based it on the earlier Leibniz assumption that \ \delta \int 2T(t)dt=0. Euler (1744) made the more fundamental assumption that \delta \int pdq=0.

Max Born | Max Born, a German physicist who played a pivotal role with Heisenberg in development of quantum matrix mechanics.

Maxwell's equations | James Maxwell formulated the classical theory of electromagnetism in his 1865 publication, "A dynamical theory of the Electromagnetic field" that unified, electricity, magnetism, and electromagnetic waves.

Michelson Morley experiment | This work showed that the velocity of light was unchanged by the motion of the Earth leading to Einstein's Special Theory of Relativity.

Minkowski metric | Minkowski space combines three-dimensional Eucliden space plus time into a four-dimensional manifold

Navier-Stokes equation | The Navier-Stokes equations are a set of partial differential equations that describe the motion of viscous fluids.

Newton's First-order integrals | (1) Linear Momentum: \mathbf{F}_{i}=\frac{d\mathbf{p}_{i}}{dt}\hspace{1in}\int_{1}^{2}\mathbf{F}_{i}dt=\int_{1}^{2}\frac{d\mathbf{p}_{i}}{dt}dt=\left(\mathbf{p}_{2}- \mathbf{p}_{1}\right) _{i} \nonumber (2) Angular momentum: \frac{d\mathbf{L}_{i}}{dt}=\mathbf{r}_{i}\times \frac{d\mathbf{p}_{i}}{dt}= \mathbf{N}_{i}\hspace{1in}\int_{1}^{2}\mathbf{N}_{i}dt=\int_{1}^{2}\frac{d \mathbf{L}_{i}}{dt}dt=\left(\mathbf{L}_{2}-\mathbf{L}_{1}\right) _{i} \nonumber (3) Kinetic energy: Thus the differential, and corresponding first integral, form of the kinetic energy can be written as \mathbf{F}_{i}=\frac{dT_{i}}{d\mathbf{r}_{i}}\hspace{1in}\int_{1}^{2}\mathbf{F}_{i}\cdot d\mathbf{r}_{i}=(T_{2}-T_{1})_{i} \nonumber

Noether's theorem. | Noether's theorem states that every differentiable symmetry of action of a physical system leads to a corresponding conservation law.

Non-cyclic Routhian | The non-cyclic Routhian complements the cyclic Routhian by behaving like a Hamiltonian for the non-cyclic variables, and behaves like a negative Lagrangian for the cyclic variable \ \mathbf{\omega } and \mathbf{J}. It is used extensively in science and engineering to describe rotational motion of rigid bodies.

Nonholonomic constraints | Nonholonomic generalized coordinates are not coupled by algebraic relations.

Noninertial frames | is a frame of reference that undergoes acceleration with respect to an inertial frame.

Norbert Weiner | He was an American mathematician who established cybernetics.

Normal modes | A normal mode of an oscillatory system is an independent pattern of motion for which all parts move sinusoidally with the same frequency and with a fixed relative phase.

Orbit equation | The orbit equation defines the path of a body m_{2} orbiting around a central body m_{1} without specifying position as a function of time.

Orbit stability | An orbit is stable if the orbit solution repeats each period.

Parallel-axis theorem | Also known as Steiner's theorem, states that the moment of inertia about a point that is a distance d from the center of mass, equals I=I_{cm}+md^{2} where I_{cm} is the moment of inertia about a parallel axis that intersects the center of mass.

Pauli exclusion principle | The Pauli exclusion principle states that no two electrons is the same atom can have identical quantum numbers.

Pericenter | For astronomical orbits the periapsis is the point of closest approach and apocenter the largest separation distance.

Perpendicular axis theorem | The moment of inertia of a plane lamina body about, an axis perpendicular to the plane of the lamina, is equal to the sum of the moments of inertia of the lamina about two axes at right angles to each other, in its own plane intersecting each other at a point where the perpendicular axis passes through it.

Phase space | In a dynamical system, phase space is a space for which all possible states can be represented with each possible state corresponding to a unique point is phase space. For mechanical systems the phase space normally lists the position and momentum variables as used by Hamiltonian mechanics.

Phase velocity | The phase velocity is the velocity that a wave front propagates in a medium. It is the velocity of any one frequency component of the wave measured with respect to a fixed point of the crest of the wave.

Plane pendulum | A pendulum bob of mass m is attached to a rigid mass-less rod of length l which swings in a plane in the gravitational field.

Poincare chaos | Poincare was the first to recognize the existence of chaos in the gravitational three-body problem.

Poincare-Bendixson theorem | This is a statement about the long-term behaviour for orbits of continuous dynamical systems on the plane, cylinder, or sphere. Given a differentiable real dynamical system defined on an open subset of the plane, every non-empty campact \omega \lim it of an orbit, is either a fixed point, a periodic orbit, or a connected set.

Poisson brackets | The Poisson bracket of any two continuous functions of generalized coordinates F(p,q) and G(p,q), is defined to be \left[F,G\right] _{qp}\equiv \sum_{i}\left(\frac{\partial F}{\partial q_{i}}\frac{\partial G}{\partial p_{i}}-\frac{ \partial F}{\partial p_{i}}\frac{\partial G}{\partial q_{i}}\right) \nonumber

Poisson's ratio | is the negative ratio of the transverse to axial strain.

Potential theory | In physics, potential theory is the study of harmonic functions. The name originated in the 19^{th} century from the fact that the gravitational and electrostatic fields could be modelled using the concepts of either gravitational or electrostatic potential.

Precession rate | In celestial mechanics, the apsidal precession rate is the precession of the line connecting the apsides.

Q-factor | In physics and engineering, the Q-factor (quality factor) is a dimensionless parameter that specifies the degree of damping of an oscillatory system. The largest Q factors correspond to the narrowest width of the frequency distribution while small Q factors correspond to a wide frequency distribution.

Queen Dido's problem | A story in Virgil's Aeneid describes the legendary Queen of Carthage who wishes to find the shape that maximizes an area assuming a fixed perimeter.

Radius of gyration | Defined as the root mean square distance of a point mass M object from the axis of rotation, that corresponds to the actual moment of inertia

Rayleigh dissipation function | Linear velocity-dependent energy dissipation can be handled by use of the Rayleigh dissipation function.

Reduced mass | Two-body interactions for the two-body system can be handled using the one-body representation which uses the concept of reduced mass.

Refractive index | The velocity of light in a medium equals the velocity of light in vacuum c divided by the refractive index for the medium.

Relativistic Doppler effect | The relativistic Doppler effect includes the change in frequency caused by the relative motion of the source and observer as predicted by the Special Theory of Relativity.

Restricted holonomic systems | Systems with constraints that are holonomic only for restricted conditions, such as one-sided constraints.

Reynolds number | The Reynolds number is the ratio of inertial forces to viscous forces in fluid flow. For low Reynold's numbers, fluid flow tends to be laminar, while for large Reynold's numbers, fluid flow tends to be turbulent.

Rheonomic constraint | Rheonomic constraints are explicitly time-dependent constraints.

Rotation matrix | A transformation matrix is a square matrix that is used to perform a rotation in Euclidean space.

Rotational invariant | An observable of a physical system that remains unchanged under a rotational transformation.

Rotational transformation | A transformation matrix is a square matrix used to perform a rotation in Euclidean space.

Routhian reduction | This is a hybrid formulation of Lagrangian mechanics plus Hamiltonian mechanics that was developed by Edward John Routh (1831-1907). Some generalized coordinates are chosen to be generalized velocities, while others are chosen to be generalized momenta. The Routhian equations are exactly the Hamiltonian equations for those coordinates respresented by generalized momenta, while the Lagrangian equations apply for the coordinates represented by velocities. This is used extensively for rotating systems in engineering.

Rutherford scattering | Lord Rutherford used scattering of \alpha particles by a thin gold foil to determine the size of the nucleus which led to development of the Bohr model of the atom.

Schrödinger equation | A linear partial differential equation that defines the wave function in quantum mechanics. Dirac incorporated the wave mechanics of Schrödinger and matrix mechanics of Heisenberg into a single formulation of quantum mechanics.

Scleronomic constraints | Equations of constraint that do not contain time as an explicit variable.

Shear modulus of elasticity | describes the shear elasticity of a material.

Signal processing | The analysis, modification, and synthesis for signal communication. It applies to analog signals, continuous time, descrete time, digital, nonlinear, and statistical, signal processing. This is an important subject in information theory and technology.

Signal velocity | The speed at which a wave carries information. The signal velocity usually equals the group velocity. However, there are situations where the group velocity exceeds c, but the signal velocity is less than c as predicted by Special Relativity.

Simultaneity | The time relation between two events happening at the same time in a given reference frame.

Slow light | Propagation of an optical pulse at a very slow group velocity due to interaction with the medium in which the light propagates.

Snell's Law | The relationship between the index of refraction n and propagation angle \theta in a given medium. n_{1}\sin \theta _{1}=n_{2}\sin \theta _{2}

Soliton | A soliton or solitary wave is a self-reinforcing wave packet that maintains its shape while it propagates at a constant velocity.

Sommerfeld quantum of action | The Bohr-Sommerfeld old quantum theory assumed that the classical action integral was quantized.

Spatial inversion transformation | This transformation is a mirror reflection.

Special theory of relativity | Einstein's Special theory of Relativity, published in 1905, states that (1) the laws of physics are invariant in all inertial frames of reference, and (2) The speed of light in vacuum is a constant of nature.

Spherical coordinates | The spherical coordinates used are r, \theta,\phi

Spherical pendulum | A mass m suspended from a line of length l that is free to oscillate in two dimensions \theta and \phi.

Spherical tensor | Spherical tensors operators are used extensively to describe observables that involve a spherical basis and spherical harmonics.

State space | The state space representation (q_{i},\dot{q}_{i} ,t) is most valuable when discussing Lagrangian mechanics.

Strain | The strain tensor is a geometric measure of the physical deformation induced by stress imposed on a continuous medium.

Stress | The elastic stress tensor is a measure of the internal forces due to deformation of a continuous medium.

Strong equivalence principle | implies that the gravitational constant applies everywhere in the universe.

Symmetric top | The symmetric top is a body that has an axis of symmetry plus two identical moments of inertia.

Symmetry tensor | The symmetry of the isotropic, harmonic, two-body, central force leads to definition of the symmetry tensor \mathbf{A\prime}, which is an invariant of motion. It defines the orientation, but not direction, of the major principle axis of the elliptical orbit.

Teleology | Any philosophy that holds that final causes exist in nature. That is, analogous to purposes found in human actions, nature inherently tends toward definite ends.

Three-body problem | This involves using the initial locations and velocities of three bodies and solving for their subsequent motion. In general no closed-form solution exists for the three-body problem. As a consequence the resulting dynamical behavior can be chaotic for most initial conditions. .

Translational invariance | Translational invariance implies that the properties do not change following a translation. Noether's theorem implies that spatial translational symmetry is equivalent to the momentum conservation law.

Turbulent flow | In fluid mechanics, turbulent flow usually is characterized by chaotic behavior of the local pressure, plus flow velocity and direction. This considerably increases drag compared to laminar fluid flow.

Twin paradox | The Special Theory of Relativity, considers two identical twins one of whom makes a long journey at high speed and then returns home to find that the twin who stayed home has aged much more than the twin who travelled.

van der Pol oscillator | Van der Pol discovered stable relaxation-oscillations in electrical circuits that are exhibited by systems in both the physical and biological sciences.

Vector differential operators | A vector differential operator, designated by the \nabla symbol, include the gradient, divergence, and curl of a function.

Vector integral calculus | Vector is concerned with differentiation and integration of vector fields.

Virial theorem | In mechanics, the virial theorem provides a general equation relating the average over time of the total kinetic energy of a system.

Virtual work | Virtual work is used in the application of the principle of least action.

Wave-particle duality | Wave-particle duality is a concept used in quantum theory that every quantum entity may be describe either as a particle or a wave.

Weak equivalence principle | This states that the inertial and gravitational masses of a matter are identical.

William Hamilton | Sir William Hamilton (1805-1865) was an Irish mathermatican who developed both the Lagrangian and Hamiltonian branches of algebraic classical mechanics.

Young's modulus of elasticity | describes tensile elasticity of a material.

Zeeman effect | The splitting of an atomic spectral line due to the interaction of the magnetic moment of an atom with the applied magnetic field. If the spin-orbit interaction dominates then the atom precesses about the total angular momentum J. However if the external magnetic field dominates over the spin-orbit coupling, then the magnetic splitting due to the atomic spin becomes is less important.