# Conservation of momentum examples pdf

Do you navigate arXiv using a screen reader or other assistive technology? Are you a professor who helps students do so? We want to hear from you. Please consider signing up to share your insights as we work to make arXiv even more open. Momentum is a vector quantity which in simple terms is defined as the product of mass and velocity. The momentum of a closed system, unless an external force is applied to the system, remains the same. This is known as the principle of conservation of momentum. It is a very important principle in mechanics as this forms the base of many scientific processes including the takeoff of rockets. Momentum is generally considered to be of two types, which are linear momentum and angular momentum. In linear momentum, we use the linear velocity and calculate the dynamics of the system in that frame of reference while in the case of angular momentum, we use angular momentum to understand the dynamics of a particular system. Both the linear momentum as well as angular momentum can be possessed by a body at the same time.The property that characterizes the rotatory inertia of an object in motion about the axis which may or may not pass through that specified object is known as angular momentum. One of the best examples of angular momentum is the Earth’s rotation and revolution. For example, the annual revolution that the Earth carries out about the Sun reflects orbital angular momentum while its everyday rotation about its axis shows spin angular momentum.Angular momentum is broadly categorized into:- The spin angular momentum. (e.g., rotation)The orbital angular momentum. (e.g. revolution)The total angular momentum of a body is the sum of spin and orbital angular momentum.It can be said that angular momentum is a vector quantity, i.e. it requires both magnitude and direction. The angular momentum possessed by a body going through orbiting motion is also said to be equal to its linear momentum. The angular momentum is also given as the product of mass (m) and linear velocity (v) of the object multiplied by the distance (r) perpendicular to the direction of its motion, i.e., mvr. But, in the case of a spinning body, the angular momentum is the summation of mvr for all the particles which make the object.Some vital things to consider about angular momentum are: Symbol = As the angular momentum is a vector quantity, it is denoted by symbol L.Units = It is measured in SI base units: Kg $m^2s^{-1}$.Dimensional formula = M $L^2$ $T^{-1}$Formula to calculate angular momentum (L) = mvr, where m = mass, v = velocity, and r = radius.Angular Momentum FormulaThe angular momentum of an object having mass (m) and linear velocity (v) with respect to a fixed point can be given as: L = mvr sin θOr \[\overrightarrow{L}\] = r x \[\overrightarrow{p}\] (in terms of vector product)Where,\[\overrightarrow{L}\] = Angular Momentumv = linear velocity of the objectm = mass of the object\[\overrightarrow{p}\] = linear momentumr = radius, i.e., distance amid the object and the fixed point around which it revolves.Moreover, angular momentum can also be formulated as the product of the moment of inertia (I) and the angular velocity (ω) of a rotating body. In this case, the angular momentum is derivable from the below expression:\[\overrightarrow{L}\] = I x ωWhere, L→is the angular momentum.I is the rotational inertia.ω is the angular velocity.The direction of the angular momentum vector, in this case, is the same as the axis of rotation of the given object and is designated by the right-hand thumb rule.Right-Hand Thumb Rule The right-hand thumb rule gives the direction of angular momentum and states that if someone positions his/her hand in a way that the fingers come in the direction of r, then the fingers on that hand curl towards the direction of rotation, and thumb points towards the direction of angular momentum (L), angular velocity, and torque.Angular Momentum and Torque For a continuous rigid object, the total angular momentum is equal to the volume integral of angular momentum density over the entire object. Here, torque is defined as the rate of change of angular momentum. Torque is related to angular momentum in a way similar to how force is related to linear momentum. Now, when we know what the angular momentum and torque are, let's see how these two are related. To see this, we need to find out how objects in rotational motion get moving or spinning in the first position.Let's take the example of a wind turbine. We all know that it's the wind that makes the turbine spins. But how is it doing so? Well, the wind is pushing the turbine's blade by applying force to blades at some angles and radius from the axis of rotation of the turbine. In simple words, the wind is applying torque to the turbine. Hence, it is torque that gets rotatable objects spinning when they are standing still. Moreover, if the torque is applied to an object which is already spinning in the same direction in which it is spinning, it upsurges its angular velocity. Hence, we can say that torque is directly proportional to the angular velocity of a rotating body. Since torque can change the angular velocity, it can also change the amount of angular momentum as the angular momentum depends on the product of the moment of inertia and angular velocity. This is how torque is related to angular momentum. Consider a string is tied to a point mass. Now, if we apply torque on the same point mass, it would start rotating around the centre. Here, the particle of mass m would move with a perpendicular velocity $V^{\perp}$ to the radius r of the circle. Now, the magnitude of \[\overrightarrow{L}\] will be:L = rmv sin ϕ = r p⊥= rmv⊥= r⊥p= r⊥mvWhere, Φ is the angle formed between \[\overrightarrow{r}\] and \[\overrightarrow{p}\]p⊥ and v⊥ are the segments of \[\overrightarrow{p}\] and \[\overrightarrow{v}\] perpendicular to \[\overrightarrow{r}\] .r⊥ is the perpendicular distance between the extension of \[\overrightarrow{p}\] and the fixed point.Note: The equation or formula L = r⊥mv representing the angular momentum of an object changes only when you apply a net torque. Hence, if no torque is applied, then the perpendicular velocity of the object will alter according to the radius (the distance between the centre of the circle, and the centre of the mass of the body). It means velocity will be high for a shorter radius and low for a longer one.  Coupling in quantum physicsCoupling in science Classical coupling Rotational–vibrational coupling Quantum coupling Ro–vibrational spectroscopy Vibronic coupling Rovibronic coupling Angular momentum coupling NMR coupling or J-coupling vte In quantum mechanics, the procedure of constructing eigenstates of total angular momentum out of eigenstates of separate angular momenta is called angular momentum coupling. For instance, the orbit and spin of a single particle can interact through spin–orbit interaction, in which case the complete physical picture must include spin–orbit coupling. Or two charged particles, each with a well-defined angular momentum, may interact by Coulomb forces, in which case coupling of the two one-particle angular momenta to a total angular momentum is a useful step in the solution of the two-particle Schrödinger equation. In both cases the separate angular momenta are no longer constants of motion, but the sum of the two angular momenta usually still is. Angular momentum coupling in atoms is of importance in atomic spectroscopy. Angular momentum coupling of electron spins is of importance in quantum chemistry. Also in the nuclear shell model angular momentum coupling is ubiquitous.[1][2] In astronomy, spin–orbit coupling reflects the general law of conservation of angular momentum, which holds for celestial systems as well. In simple cases, the direction of the angular momentum vector is neglected, and the spin–orbit coupling is the ratio between the frequency with which a planet or other celestial body spins about its own axis to that with which it orbits another body. This is more commonly known as orbital resonance. Often, the underlying physical effects are tidal forces. General theory and detailed origin Orbital angular momentum (denoted l or L). Angular momentum conservation Conservation of angular momentum is the principle that the total angular momentum of a system has a constant magnitude and direction if the system is subjected to no external torque. Angular momentum is a property of a physical system that is a constant of motion (also referred to as a conserved property, time-independent and well-defined) in two situations: The system experiences a spherically symmetric potential field. The system moves (in quantum mechanical sense) in isotropic space. In both cases the angular momentum operator commutes with the Hamiltonian of the system. By Heisenberg's uncertainty relation this means that the angular momentum and the energy (eigenvalue of the Hamiltonian) can be measured at the same time. An example of the first situation is an atom whose electrons only experience the Coulomb force of its atomic nucleus. If we ignore the electron–electron interaction (and other small interactions such as spin–orbit coupling), the orbital angular momentum l of each electron commutes with the total Hamiltonian. In this model the atomic Hamiltonian is a sum of kinetic energies of the electrons and the spherically symmetric electron–nucleus interactions. The individual electron angular momenta li commute with this Hamiltonian. That is, they are conserved properties of this approximate model of the atom. An example of the second situation is a rigid rotor moving in field-free space. A rigid rotor has a well-defined, time-independent, angular momentum. These two situations originate in classical mechanics. The third kind of conserved angular momentum, associated with spin, does not have a classical counterpart. However, all rules of angular momentum coupling apply to spin as well. In general the conservation of angular momentum implies full rotational symmetry (described by the groups SO(3) and SU(2)) and, conversely, spherical symmetry implies conservation of angular momentum. If two or more physical systems have conserved angular momenta, it can be useful to combine these momenta to a total angular momentum of the combined system—a conserved property of the total system. The building of eigenstates of the total conserved angular momentum from the angular momentum eigenstates of the individual subsystems is referred to as angular momentum coupling. Application of angular momentum coupling is useful when there is an interaction between subsystems that, without interaction, would have conserved angular momentum. By the very interaction the spherical symmetry of the subsystems is broken, but the angular momentum of the total system remains a constant of motion. Use of the latter fact is helpful in the solution of the Schrödinger equation. Examples As an example we consider two electrons, in an atom (say the helium atom) labeled with i = 1 and 2. If there is no electron–electron interaction, but only electron–nucleus interaction, then the two electrons can be rotated around the nucleus independently of each other; nothing happens to their energy. Both operators, l1 and l2, are conserved. However, if we switch on the electron–electron interaction that depends on the distance d(1,2) between the electrons, then only a simultaneous and equal rotation of the two electrons will leave d(1,2) invariant. In such a case neither l1 nor l2 is a constant of motion in general, but the total orbital angular momentum L = l1 + l2 is. Given the eigenstates of l1 and l2, the construction of eigenstates of L (which still is conserved) is the coupling of the angular momenta of electrons 1 and 2. The total orbital angular momentum quantum number L is restricted to integer values and must satisfy the triangular condition that | l 1 − l 2 | ≤ L ≤ l 1 + l 2 {\displaystyle |l_{1}-l_{2}|\leq L\leq l_{1}+l_{2}} , such that the three nonnegative integer values could correspond to the three sides of a triangle.[3] In quantum mechanics, coupling also exists between angular momenta belonging to different Hilbert spaces of a single object, e.g. its spin and its orbital angular momentum. If the spin has half-integer values, such as 1/2 for an electron, then the total (orbital plus spin) angular momentum will also be restricted to half-integer values. Reiterating slightly differently the above: one expands the quantum states of composed systems (i.e. made of subunits like two hydrogen atoms or two electrons) in basis sets which are made of tensor products of quantum states which in turn describe the subsystems individually. We assume that the states of the subsystems can be chosen as eigenstates of their angular momentum operators (and of their component along any arbitrary z axis). The subsystems are therefore correctly described by a pair of ℓ, m quantum numbers (see angular momentum for details). When there is interaction among the subsystems, the total Hamiltonian contains terms that do not commute with the angular operators acting on the subsystems only. However, these terms do commute with the total angular momentum operator. Sometimes one refers to the non-commuting interaction terms in the Hamiltonian as angular momentum coupling terms, because they necessitate the angular momentum coupling. Spin–orbit coupling Main article: Spin–orbit coupling The behavior of atoms and smaller particles is well described by the theory of quantum mechanics, in which each particle has an intrinsic angular momentum called spin and specific configurations (of e.g. electrons in an atom) are described by a set of quantum numbers. Collections of particles also have angular momenta and corresponding quantum numbers, and under different circumstances the angular momenta of the parts couple in different ways to form the angular momentum of the whole. Angular momentum coupling is a category including some of the ways that subatomic particles can interact with each other. In atomic physics, spin–orbit coupling, also known as spin-pairing, describes a weak magnetic interaction, or coupling, of the particle spin and the orbital motion of this particle, e.g. the electron spin and its motion around an atomic nucleus. One of its effects is to separate the energy of internal states of the atom, e.g. spin-aligned and spin-antialigned that would otherwise be identical in energy. This interaction is responsible for many of the details of atomic structure. In solid-state physics, the spin coupling with the orbital motion can lead to splitting of energy bands due to Dresselhaus or Rashba effects. In the macroscopic world of orbital mechanics, the term spin–orbit coupling is sometimes used in the same sense as spin–orbit resonance. LS coupling Illustration of L–S coupling. Total angular momentum J is purple, orbital L is blue, and spin S is green. In light atoms (generally Z ≤ 30[4]), electron spins si interact among themselves so they combine to form a total spin angular momentum S. The same happens with orbital angular momenta ℓi, forming a total orbital angular momentum L. The interaction between the quantum numbers L and S is called Russell–Saunders coupling (after Henry Norris Russell and Frederick Saunders) or LS coupling. Then S and L couple together and form a total angular momentum J:[5][6] J = L + S , {\displaystyle \mathbf {J} =\mathbf {L} +\mathbf {S} ,\,} where L and S are the totals: L = ∑ i ℓ i ,   S = ∑ i s i . {\displaystyle \mathbf {L} =\sum _{i}{\boldsymbol {\ell }}_{i},\ \mathbf {S} =\sum _{i}\mathbf {s} _{i}.\,} This is an approximation which is good as long as any external magnetic fields are weak. In larger magnetic fields, these two momenta decouple, giving rise to a different splitting pattern in the energy levels (the Paschen–Back effect), and the size of LS coupling term becomes small.[7] For an extensive example on how LS-coupling is practically applied, see the article on term symbols. jj coupling In heavier atoms the situation is different. In atoms with bigger nuclear charges, spin–orbit interactions are frequently as large as or larger than spin–spin interactions or orbit–orbit interactions. In this situation, each orbital angular momentum ℓi tends to combine with the corresponding individual spin angular momentum si, originating an individual total angular momentum ji. These then couple up to form the total angular momentum J J = ∑ i j i = ∑ i ( ℓ i + s i ) . {\displaystyle \mathbf {J} =\sum _{i}\mathbf {j} _{i}=\sum _{i}({\boldsymbol {\ell }}_{i}+\mathbf {s} _{i}).} This description, facilitating calculation of this kind of interaction, is known as jj coupling. Spin–spin coupling See also: J-coupling, Dipolar coupling, and NMR spectroscopy Spin–spin coupling is the coupling of the intrinsic angular momentum (spin) of different particles. J-coupling between pairs of nuclear spins is an important feature of nuclear magnetic resonance (NMR) spectroscopy as it can provide detailed information about the structure and conformation of molecules. Spin–spin coupling between nuclear spin and electronic spin is responsible for hyperfine structure in atomic spectra.[8] Term symbols Main article: Term symbol Term symbols are used to represent the states and spectral transitions of atoms, they are found from coupling of angular momenta mentioned above. When the state of an atom has been specified with a term symbol, the allowed transitions can be found through selection rules by considering which transitions would conserve angular momentum. A photon has spin 1, and when there is a transition with emission or absorption of a photon the atom will need to change state to conserve angular momentum. The term symbol selection rules are: ΔS = 0; ΔL = 0, ±1; Δl = ± 1; ΔJ = 0, ±1 . The expression "term symbol" is derived from the "term series" associated with the Rydberg states of an atom and their energy levels. In the Rydberg formula the frequency or wave number of the light emitted by a hydrogen-like atom is proportional to the difference between the two terms of a transition. The series known to early spectroscopy were designated sharp, principal, diffuse, and fundamental and consequently the letters S, P, D, and F were used to represent the orbital angular momentum states of an atom.[9] Relativistic effects In very heavy atoms, relativistic shifting of the energies of the electron energy levels accentuates spin–orbit coupling effect. Thus, for example, uranium molecular orbital diagrams must directly incorporate relativistic symbols when considering interactions with other atoms. [citation needed] Nuclear coupling In atomic nuclei, the spin–orbit interaction is much stronger than for atomic electrons, and is incorporated directly into the nuclear shell model. In addition, unlike atomic–electron term symbols, the lowest energy state is not L − S, but rather, ℓ + s. All nuclear levels whose ℓ value (orbital angular momentum) is greater than zero are thus split in the shell model to create states designated by ℓ + s and ℓ − s. Due to the nature of the shell model, which assumes an average potential rather than a central Coulombic potential, the nucleons that go into the ℓ + s and ℓ − s nuclear states are considered degenerate within each orbital (e.g. The 2p3/2 contains four nucleons, all of the same energy. Higher in energy is the 2p1/2 which contains two equal-energy nucleons). See also Clebsch–Gordan coefficients Angular momentum diagrams (quantum mechanics) Spherical basis Notes ^ R. Resnick, R. Eisberg (1985). 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Atomic Spectra and Atomic Structure. New York: Dover. pp. 54–55. ISBN 0-486-60115-3. External links LS and jj coupling Term symbol Web calculator of spin couplings: shell model, atomic term symbol Retrieved from "

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