Introduction

Conventions used for alphabetization and the dictionary are explained here.

Entries are bolded and if a term in the definition is bolded, then it has an entry in the dictionary. For example, the entry **absolute zero** talks about thermodynamics, and because there is an entry on **thermodynamics**, it is bolded in the defintion. A bolded term's entry in the dictionary is guaranteed; if a concept is not bolded, it may or may not be contained elsewhere in the dictionary.

Alphabetization rules are given as the following. Given spaces in a word, each is alphabetized before the space first, and then after the space. For example, for two hypothetical entries **car shoe** and **card shoe**, **car shoe** would come before **card shoe**.

Hyphens and apostrophes are treated as spaces, but with spaces first, apostrophes second, and hyphens last. So for three entries **car shoe**, **car-shoe**, **car'shoe**, the order would be **car shoe**, **car'shoe**, **car-shoe**.

Mathematically, I employ both **Newton's dot notation** and **Lagrange's prime notation** throughout in additon to the standard **Leibniz notation**.

Generally speaking, one will also find that vectors are denoted with bold face, such as **A** or **B**, while scalar values would be A or B. Tensors are denoted as $\overleftrightarrow{\mathbf{A}}$ (for a second-rank tensor) or A_{ij} with the number of indices showing the rank of the tensor (and number of contravariant and covariant entries).

For vector derivatives, ∇ is often employed, but use is also made of

$$\frac{\partial}{\partial \mathbf{x}} = \nabla$$
$$\frac{\partial}{\partial \mathbf{v}} = \nabla_v = \hat{\mathbf{x}}\frac{\partial}{\partial v_x} + \hat{\mathbf{y}}\frac{\partial}{\partial v_y} + \hat{\mathbf{z}}\frac{\partial}{\partial v_z}$$

Foreword

When I first began studying plasma physics, I had a difficult time remembering all of the acronyms and remembering what every term used meant exactly. I had hoped there would be a resource that would briefly define plasma physics terms and acronyms. Unfortunately, there were few such resources. Although the plasma physics dictionary online was somewhat helpful, it was woefully inadequate in number of entries. So I decided to keep track of terms myself and define them. The selection of terms is still rather arbitrary and not complete, but I hope more complete than any other resource. One may wonder what the utility of such a resource is in the days of Google and Wikipedia, but I often find such results to be underdeveloped. And there is still quite a bit not easily accessible, even on the internet. I hope that the definitions are of some help to others and welcome any feedback (esp. if there are any errors).

Also feel free to share this document without worries so long as you give me proper credit and do not try to profit from it without my explicitly given and written permission.

—K. J. Bunkers

April 3, 2020

a

A a

a fortiori Latin for "from the stronger", it refers to expressing a conclusion for which there is stronger evidence than a previously accepted conclusion.

a posteriori Latin for "from the later", it indicates an argument that relies on justification from empirical evidence. Often in scientific argument, one justifies *a posteriori* by making an assumption and then later justifiying the assumption was valid (i.e., consisitent) after doing the calculation.

a priori Latin for "from the earlier", it indicates an argument that does not rely on empirical evidence, but from earlier principles and logical deduction.

absolute zero The smallest possible temperature corresponding to no kinetic energy in a system, with all particles at rest. Impossible to achieve because of **quantum mechanics**, and by the **Third Law of Thermodynamics**.

action In physics, this is an abstract concept associated with the dynamical trajectory of a system. It is usually denoted S and has as its definition $S = \int_a^b L\,\mathrm{d}t$ where L is the **Lagrangian**.

adiabatic (1) A process changing slowly enough that the system has time to adapt to the new configuration. (2) (thermodynamics) A process occuring without exchange of heat.

adiabatic closure A **closure** for the fluid hierarchy where $\frac{\mathrm{d}}{\mathrm{d}t}(P/\rho^\gamma) = 0$ with $\frac{\mathrm{d}}{\mathrm{d}t}$ the full time derivative, P the **pressure**, ρ the **mass density**, and γ the **adiabatic index**. Note, this can be simplified to $\frac{\mathrm{d}P}{\mathrm{d}t} = -\gamma P \boldsymbol{\nabla} \cdot \mathbf{V}$ in the fluid hierarchy with the same definitions and $\boldsymbol{\nabla} \cdot \mathbf{V}$ being the **divergence** of the **flow velocity**. Note that another way of saying this is that dynamics are fast compared to thermal dynamics, or **thermal conduction** is small.

adiabatic electrons See **electron adiabaticity**

adiabatic index This is variously known as the **heat capacity ratio**, **ratio of specific heats**, **Poisson constant**, and sometimes **isentropic expansion factor**. It is usually denoted as either γ (esp. for ideal gases) or κ (often for real gases). It is given by the heat capacity at constant pressure (C_P) over the heat capacity at constant volume (C_P), or the ratio of specific heat capacities at constant pressure or volume (c_P or c_V, respectively, i.e., $\gamma = C_P/C_V = c_P/c_V$.

adiabatic invariant A quantity that is conserved under adiabatic conditions. In plasma physics, there are three called the **magnetic moment** (μ), the **longitudinal invariant** or the **bounce invariant** (J), and the **magnetic flux** (Φ).

Alfvén time This is the characteristic time it takes an Alfvén wave to propagate across some length (usually a device; for a torus, this characteristic length is usually the **major radius** or **minor radius**). It is denoted $\tau_A = L/v_A$ where L is the characteristic length and v_A is the **Alfvén speed**.

Alfvén velocity This is the speed at which an Alfvén wave propagates, usually denoted v_A. It is defined by $v_A^2 = \frac{B^2}{\mu_0 \rho}$ (SI) or $v_A^2 = \frac{B^2}{4\pi\rho}$ (Gaussian) where B is the magnetic field strength and ρ is the mass density of the plasma. (Sometimes called Alfvén speed)

Alfvén, Hannes A prominent Swedish plasma physicist who won the Nobel Prize for his work in plasma physics in 1970. Currently (2020) the only person to get a Nobel Prize for work in plasma physics (in magnetohydrodynamics).

ambipolar diffusion Process where both ions and electrons diffuse out at the same rate.

ambipolar potential An electric potential set up by differential diffusion of electrons and ions, which then enforces **ambipolar diffusion**.

anomalous transport This is transport in the plasma not predicted by **classical transport** or **neoclassical transport**. It is currently believed to be due to turbulence, and so is sometimes called **turbulent transport**.

antisymmetric tensor A tensor whose transpose is equal to the negative of itself. For tensor $\overleftrightarrow{\mathbf{T}}$, then $T_{ij} = -T_{ji}$, or $\overleftrightarrow{\mathbf{T}} = -\overleftrightarrow{\mathbf{T}}^\intercal$ for $\intercal$ meaning transpose.

aspect ratio (1) In a toroidal confinement device, the ratio of the **major radius** (R) to the **minor radius** (r). Often denoted $A = \frac{R}{r}$. It's inverse is usually denoted $\epsilon = A^{-1}$ and called the **inverse aspect ratio**. (2) In inertial confinement, the ratio of the radius of the fuel or target to the shell thickness.

atled See **nabla**.

atomic density See **number density**.

attenuation The reduction in intensity or amplitude of some quantity. Also used in verb form of attenuate.

axial vector This is a quantity that transforms like a typical **vector** under rotation of coordinates, but does not flip sign under reflection of coordinates. A simple example of an axial vector is for two **polar vectors a**

a

and **b**, the vector **c** given by $\mathbf{c} = \mathbf{a} \times \mathbf{b}$. For example, angular momentum is an axial vector.

azimuthal angle The angle in spherical coordinates that measures the angle in the x-y plane. Usually denoted as either φ or θ, with the former preferred by physicists. Usually the angle in the x-y plane is called the azimuth in other coordinate systems (cylindrical) as well, although there φ and θ are interchangeably used. See figure 1.

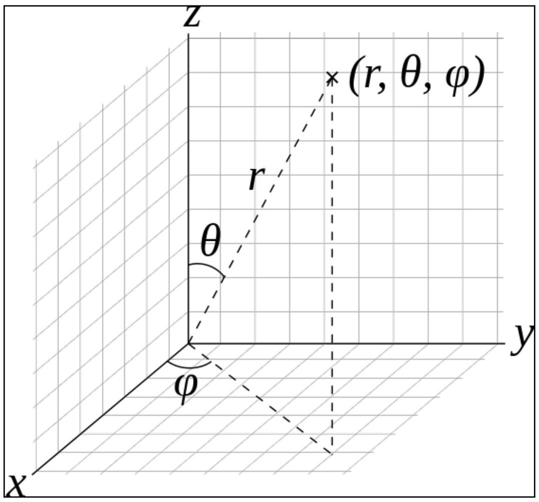

Figure 1: The azimuthal angle φ and the polar angle θ in spherical coordinates. This is an image freely available from Wikipedia.

b

B b

bad curvature Refers to areas of plasma where the **field line curvature** and pressure gradient drive are unfavorable to stability. The field line curvature is then called "bad." Quantitatively, $\boldsymbol{\kappa} \cdot \nabla p > 0$ is a bad curvature region with $\boldsymbol{\kappa}$ the **field line curvature** or **magnetic curvature**.

BAE See **beta induced Alfvén eigenmode**.

ballooning instability See **ballooning mode**.

ballooning mode A type of plasma mode/instability that occurs in bad curvature regions that is present when $\beta > \beta_c$, i.e., some critical beta (β_c). It is a multidimensional interchange effect. So called because it looks like elongations formed in a balloon when squeezed. Another way of thinking about it, is an instability due to **plasma pressure** and **curvature drift** outward and the stress due to field lines inward.

ballooning mode instability See **ballooning mode**.

banana orbit This is the orbit of a single particle when **neoclassical diffusion** effects are important. So called because the orbit looks like a banana when looking at a poloidal cross section. See Figure 2.

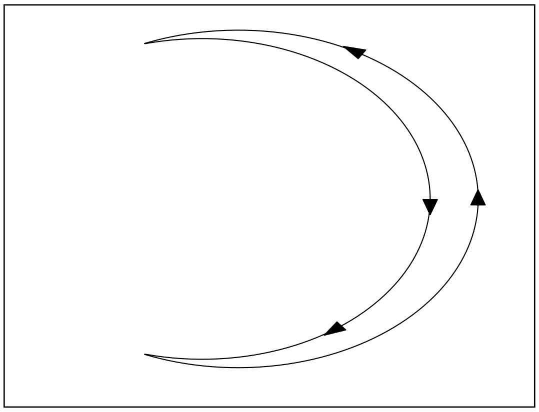

Figure 2: Poloidal cross section of a banana orbit of particle.

BBGKY hierarchy This is a hierarchy of equations for a large number of interacting particles, such that the mth moment depends on the $(m+1)$th moment. Named after Bogoliubov, Born, Green, Kirkwood, and Yvon.

Bernstein waves These are purely electrostatic **plasma waves** that occur in **magnetized hot plasmas** (and are not predicted by the magnetized cold plasma theory). These waves have resonances at $n\Omega$ where n is an integer and Ω is the cyclotron frequency in regimes where $k_\perp \rho \sim \mathcal{O}(1)$ where $k_\perp$ is the wavenumber perpendicular to the magnetic field direction and ρ is the **Larmor radius**. There are ion and electron Berstein waves depending upon ρ being ρ_i or ρ_e. In fusion, electron Berstein waves are important because they have no density cutoff and can efficiently input heat into the electrons in the plasma, which then transfer the heat to ions through collisions. The disadvantage to this method of heating is that it requires a thermal/hot plasma and requires **mode conversion**.

beta (normalized) See **normalized beta**.

beta (plasma) The ratio of plasma pressure to magnetic pressure, $\beta = \dfrac{2\mu_0 P}{B^2}$ (SI) or $\beta = \dfrac{8\pi P}{B^2}$ (Gaussian).

beta (poloidal) The ratio of plasma pressure to the magnetic field strength in the poloidal direction, B_P, which is used often in tokamaks and can approach 1. $\beta_\mathrm{P} = \dfrac{B_\mathrm{T}^2}{B_\mathrm{P}^2}\beta$.

beta induced Alfvén eigenmode Often denoted **BAE**. These are discrete Alfvén eigenmodes that are caused by coupling of poloidal modes and finite β (finite pressure) effects.

beta limit See **Troyon limit**.

binormal vector For both the **Frenet-Serret frame** and **Darboux frame**, this is the vector perpendicular to the **tangent vector** and **normal vector**.

blob Also called **filament**. A blob is a plasma structure that is hotter and denser than the surrounding plasma, usually seen in the **scrape off layer** (SOL), that are coherently aligned with the magnetic field structure.

BMI See **ballooning mode**. Stands for **ballooning mode instability**.

Bogoliubov hierarchy See **BBGKY hierarchy**.

Bohm criterion This is the assumption that ions are accelerated to the **sound speed** at the entrance of a **plasma sheath**. This is often applied in the **scrape off layer** (**SOL**).

Bohm diffusion Diffusion characterized by a **diffusion constant** D_Bohm of $\dfrac{k_B T}{16eB}$ where k_B is the Boltzmann constant, T is the temperature in Kelvin, e is the charge, and B is the magnetic field. Note this b

scaling is unfavorable for confinement. Named after David Bohm who observed it with, E. H. S. Burhop, and Harrie Massey.

Bohm scaling Scaling of the diffusion constant in plasma physics where the diffusion constant, D has $D \propto \frac{1}{B}$ where B is the magnetic field intensity. See **Bohm diffusion**.

Bohm sheath criterion See **Bohm criterion**.

Bohr-van Leeuwen theorem A theorem that states in **classical physics** the thermal average of the **magnetization** is zero. That is, the magnetization is always zero in equilibrium.

Boltzmann relation In plasma physics, this is the relation for electrons that $n_e(V_1) = n_e(V_2)\exp\left(\frac{e(V_1-V_2)}{k_B T_e}\right)$ where n_e is electron **number density**, (V_1, V_2) are electrostatic potentials at two locations, T_e is electron temperature, and k_B is the Boltzmann constant. This is simply a result of thermodynamics with the Gibbs or canonical ensemble.

bootstrap current A current parallel to the magnetic field due to neoclassical effects. It is associated with trapped particles in **banana orbits**. The differing particle densities on parts of banana orbits drives the current. It is called bootstrap, because the current appears to form spontaneously in the plasma, and so the plasma current is "pulling itself up by its bootstraps", seemingly in defiance of normal physics (pulling yourself up by your bootstraps would violate **Newton's third law** of motion).

bounce average An average for **trapped particles** that averages between the **bounce points**.

bounce frequency This is the (angular) frequency for particles moving between two **bounce points**. Usually denoted $\omega_b = \frac{2\pi}{\tau_b}$. Note that it is the angular frequency, not $\nu_b = \frac{1}{\tau_b}$ that is usually called the bounce frequency.

bounce invariant See **longitudinal invariant**.

bounce point A point in the trajectory for a **trapped particle** where it reverses its velocity.

bounce time This is the time between a particle moving from one **bounce point** to the next bounce point. Usually denoted τ_b.

Bremsstrahlung Radiation caused by charged particles decelerating/accelerating by being scattered by another chrarged particle. Note this process has a continuous spectrum. Comes from German *bremsen* ("to brake") and *Strahlung* ("radiation").

bulk modulus The change in unit volume per unit volume under the influence of unit normal pressure applied from all sides. This is given by $\kappa = \frac{3(1-2\sigma)}{E}$ where κ is the bulk modulus, E is **Young's modulus** and σ is **Poisson's ratio**.

burning plasma In thermonuclear fusion, this is a plasma where an appreciable amount of heating of the plasma comes from the fusion reactions themselves. It is not enough to require no external heating, an **ignited plasma**. Typically a $Q \geq 5$ is considered a burning plasma.

C

C c

canonical coordinates These are coordinates where the coordinates are **canonical variables** and for each canonical coordinate there is a **canonically conjugate** coordinate.

canonical transformation A transformation of **canonical coordinates** to a new set of different canonical coordinates.

canonical variables These are variables that satisfy the relation $\{q_i\,,\,q_i\} = \{p_i\,,\,p_i\} = 0$ (note there is no summation here) and $\{q_i\,,\,p_j\} = \delta_{ij}$ where $\{\cdot,\cdot\}$ is the **Poisson bracket** and δ_{ij} is the **Kronecker delta**.

canonically conjugate This means that for a variable, q, the canonically conjugate variable, p, satisfies the relations (if there are N variables and so N canonically conjugate variables, let q_i be one of the N variables) $\{q_i\,,\,q_i\} = \{p_i\,,\,p_i\} = 0$ and $\{q_i\,,\,p_i\} = \delta_{ij}$ where $\{\cdot,\cdot\}$ is the **Poisson bracket** and δ_{ij} is the **Kronecker delta**. For example, given a **generalized coordinate** q we say the canonically conjugate **(generalized) momentum** to q is p where $p = \frac{\partial L}{\partial \dot{q}}$ with L the **Lagrangian**. Also see **conjugate variables**.

Cauchy principal value This is the principal value of an integral, defined for integrals that would not usually converge. That is, it gives a way of assigning values to non-convergent integrals. It is often symbolized as $⨍ \mathrm{d}x\ f(x)$, $PV \int \mathrm{d}x\ f(x)$, $\mathcal{P} \int \mathrm{d}x\ f(x)$, $\int_L^* \mathrm{d}x\ f(x)$, P.V. $\int \mathrm{d}x\ f(x)$, $P \int \mathrm{d}x\ f(x)$, $P_v \int \mathrm{d}x\ f(x)$, p.v. $\int \mathrm{d}x\ f(x)$, $CPV \int \mathrm{d}x\ f(x)$, and P.V. $\int \mathrm{d}x\ f(x)$. The definition of the principal value is dependent upon the type of singularity it is avoiding. In plasma physics, this definition is usually given by $⨍_a^c \mathrm{d}x\ f(x) = \lim_{\epsilon\to 0^+} \left(\int_a^{b-\epsilon} f(x) + \int_{b+\epsilon}^c f(x) \right)$ with the singularity at b with $a < b < c$.

Cauchy sequence A **sequence** $x_1, x_2, \dots$ such that for every $\epsilon > 0$ there exists an N such that $d(x_m - x_n) < \epsilon$ for all $m, n > N$ where d is the metric function for the **metric space** the x_i belong to.

centrifugal force A force in a noninertial rotating frame, that shows up to correct for the frame being non-inertial. It is usually denoted for an angular velocity of $\boldsymbol{\omega}$ as $\boldsymbol{\omega} \times (\boldsymbol{\omega} \times \mathbf{r})$.

cf Latin. Short for *confer*. It translates as "compare". Sometimes it is given as cp.

CGL pressure tensor Chew, Goldberger, and Low. A pressure **tensor** of the form $\overleftrightarrow{\mathbf{P}}_{\mathrm{CGL}} = \mathbf{I}P_\perp + \hat{\mathbf{b}}\hat{\mathbf{b}}P_\Delta$ where $\hat{\mathbf{b}}\hat{\mathbf{b}}$ is a **dyad** with the unit vector $\hat{\mathbf{b}}$ pointing in the direction of magnetic field, $\mathbf{I}$ is the identity tensor, and $P_\Delta = P_\parallel - P_\perp$. This is for pressure anisotropy.

CGS Could be one of many of the systems with base units centimeter (cm), gram (g), and second (s). Generally, refers to **Gaussian** units when talking about electromagnetism.

cgs See **CGS**.

Chandrasekhar number This is a dimensionless number of plasma physics denoted $Q = \frac{B^2 L^2}{\rho\eta\nu}$ where B is a characteristic magnetic field, L is a characteristic length, ρ is a mass density, η is electrical resistivity, and ν is **kinematic viscosity**. It can be interpreted as $Q = \frac{\text{magnetic}}{\text{dissipation}}$ force.

characteristic function See **eigenfunction**.

characteristic value See **eigenvalue**.

characteristic vector See **eigenvector**.

circa Latin. Often shortened to *c.*, *ca.* or *cca.*. This translates as "about", "approximately", or "around" and is typically used with dating.

circulating particle See **passing particle**.

circulation When a particle (especially in fluid dynamics) undergoes motion in a circle, circulation is a way of measuring this motion. That is, the particles flow around some imaginary axis. It is often defined as $\Gamma = \int_A \mathrm{d}a\boldsymbol{\omega} \cdot \hat{\mathbf{n}} = \int_C \mathrm{d}\boldsymbol{\ell} \cdot \mathbf{u}$ where A is the area to be integrated over, $\hat{\mathbf{n}}$ is the surface normal for the area, and $\boldsymbol{\omega} = \boldsymbol{\nabla} \times \mathbf{u}$ is the **vorticity**, C is the curve bounding A, $\mathrm{d}\boldsymbol{\ell}$ is an element along C and $\mathbf{u}$ is the **flow velocity**.

classical diffusion This is diffusion based only on scattering of charged particles through the Coulomb interaction and neutrals through collisions (it does not take into account confining geometry, for example).

classical physics Sometimes called **Newtonian physics**, this is physics that deals with continuous real values rather than the discretization of **quantum mechanics** and with velocities much smaller than the speed of light.

classical transport See also **classical diffusion**. This involves all transport processes that are based on scattering of charged particles through the Coulomb interaction and neutral particles through collisions without taking account of confining geometry (such as a toroidal confining geometry).

closed field line A field line that closes in on itself. That is a field line that "bites its tail".

closed flux surface A **flux surface** that forms a closed surface.

closed system A system that cannot exchange matter outside of the system's boundaries. It can exchange energy.

closure This is an equation that closes a system of equations, so that all variables can be solved for. In plasma physics, common closures for the fluid moment hierarchy are the **incompressible closure**, **adiabatic closure**, and **isothermal closure**.

CMA diagram A Clemmow-Mullaly-Allis diagram. Sometimes called an Allis diagram. This is a diagram that shows (for different frequencies ω) the different conditions that various plasma waves can propagate in. The vertical axis is the $\Omega_e/\omega \propto B$, i.e., the electron **cyclotron frequency** over the frequency of interest which is proportional to the magnetic field. The horizontal axis is ω_p/ω, i.e., the **plasma frequency** over the frequency of interest which is proportional to the **number density**. There are 4 main regions to a CMA diagram with the lower left referring to high frequency waves and the upper right to low frequency waves. In addition, in each of the subregions we see the ellipses and figure eights. These give information on the propagation of the different types of waves in each region. The L refers to **left circularly polarized wave**; R for **right circularly polarized wave**; O for **ordinary**; X for **extraordinary wave**. The relative distance of a an ellipse or figure eight from the center of the circle/figure eight gives how large the phase velocity. That is for that angle (measured from the horizontal counterclockwise [which measures the angle between the magnetic field and the wave vector **k**]) the distance from the center gives relative phase velocity of the wave. So for the region farthest up and to the right we see that 3 waves exist with the R mode and X mode having greater phase velocities than the L mode. The L mode being when the wave vector is perpendicular to the magnetic field. The R mode also exists and is when the wave vector and magnetic field are perpendicular. We also see that no O mode exists as it is a figure eight for the inner L curve, and so the phase velocity is "zero" for the O mode (it is not a wave). See Figure 3.

coefficient of thermal expansion A measure of how much an object changes in volume when subjected to a changing temperature. It is denoted principally by α but sometimes β is used.

coefficient of viscosity See **viscosity**.

cold plasma This cold refers to the temperature of the ions and electrons and are cold in the sense that

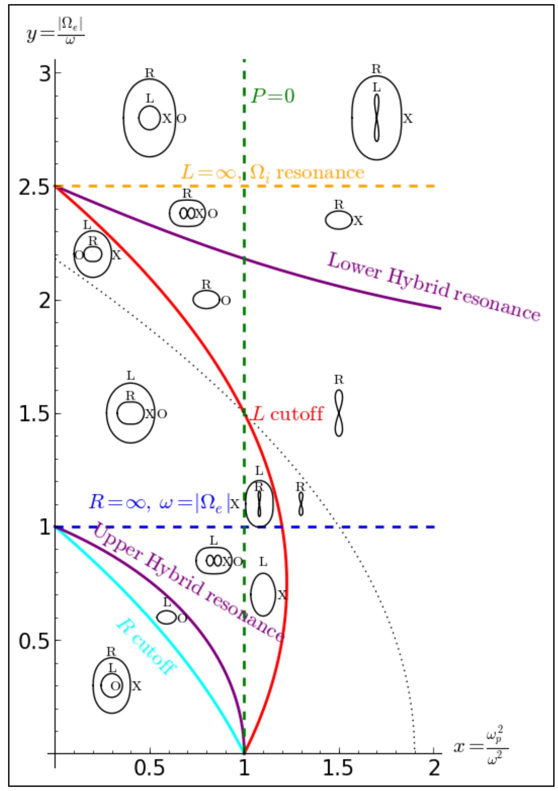

Figure 3: CMA diagram. Here the mass ratio was chosen to be $m_i/m_e = 3$ with $Z_i/Z_e = -1$ where Z_i is the charge of the ion and Z_e is the charge of the electron.

these temperatures are near the ionization temperatures. A cold plasma then tends to be weakly ionized.

collision frequency This is the number of collisions a typical particle undergoes in a time period. Usually denoted ν. This is inversely related to the **collision time** and is the particle's velocity divided by the **mean free path**.

collision operator This is an operator on the **distribution function** that modifies the **Vlasov equation** for the evolution of the **distribution function**. Often denoted $\frac{\partial f}{\partial t}|_{\text{coll.}}$ or $C(f)$. It represents particles scattering and/or colliding with each other.

collision time This is the typical time it takes for a particle to undergo one collision (after just having had a collision). It is usually denoted τ. It is dependent on the particle species involved. It is the inverse of the **collision frequency** and equal to the **mean free path** divided by the particle's velocity.

collisionality This is a dimensionless parameter comparing the electron-ion **collision frequency** to the banana orbit frequency given by $\nu^* \equiv \nu_{ei}\sqrt{\frac{m_i}{k_B T_i}}\epsilon^{-3/2}qR$ with R the **major radius**, q the **safety factor**, and ϵ the **inverse aspect ratio** and $\nu^* \sim T^{-2}$ (and scales independently of mass). It is also

connection length over the trapped particle **mean free path** (estimated by **thermal velocity** divided by **collision frequency**).

collisionless plasma This is plasma where collisions occur infrequently enough for the process being studied, that collisions can be ignored. This can be due to low density or the plasma being very hot (i.e., high temperature).

collisionless tearing mode These are **tearing modes** that have a dispersion relation of the form $\omega - \omega_{*e} \sim ik'_{\|} v_{\mathrm{th}_e}(c/\omega_{pe})^2\Delta'$ for small Δ', where ω_{*e} is the electron **drift frequency**, $k'_{\|}$ is the derivative of the wavevector along the magnetic field direction, v_{th_e} is the electron **thermal velocity**, c is the speed of light, ω_{pe} is the electron **plasma frequency**, and Δ' is a parameter (called **Delta-prime**) used to determine the stability of modes in tearing and twisting modes.

compact toroid A toroidal plasma configuration that does not require magnetic coils running through the center of the device. This is called self-stable.

Compact Toroidal Hybrid Shortened to **CTH**. A **torsatron** in Auburn, Alabama.

complete metric space A **space** such that every **Cauchy sequence** converges within the space.

complex plasma See **dusty plasma**.

compressional Alfvén wave See **magnetoacoustic wave**.

compressive strain A **normal strain** that tends to compress the object or decrease its length in a certain direction.

compressive stress A **normal stress** that tends to compress the object (so "inward" force).

confinement time See **energy confinement time**.

conjugate variables Conjugate variables are variables which are **Fourier duals** of each other.

connection length This is the length between two points as traversed by a magnetic field line. For fusion, there are two cases of interest. For **closed flux surfaces** in a circular **tokamak** it is usually defined as the length to complete a poloidal turn given by $L = 2\pi r \frac{B_\phi}{B_\theta} = 2\pi Rq$ with r the **minor radius**, R the major radius, ϵ the **inverse aspect ratio**, and B_ϕ, B_θ the toroidal and poloidal magnetic fields, respectively. For **open flux surfaces**, it is the shortest distance from the point to a material surface along magnetic field lines.

conservative force A force which has the property that the amount of work done by moving the particle under the force depends only on the initial and final locations of the particle. It means that the force can be represented by the negative gradient of a **scalar potential**.

constitutive relations Relations between two physical quantities specific to a substance.

contravariant When referring to a vector $\mathbf{v}$'s specified components, v^i is contravariant when it transforms under change of coordinates as $\tilde{v}^i = \frac{\partial \xi^i}{\partial x^j} v^j$ where x^i are the original vector basis and ξ^i is the new coordinate basis. Contravariant indices in **Einstein summation notation** are denoted with a superscript. They are called contravariant because if you change your unit of measure (say from millimeters to meters), the components vary "against" the change (so your component $\tilde{v}^i$ in meters will be 1/1000 of the original v^i in millimeters, even though millimeters to meters is a factor of 1000). In general, a component of a tensor is called contravariant if that component transforms as above for a coordinate change. Many sources call vectors contravariant. In those cases, vectors are identified as an array of numbers corresponding to what is here called a representation of a vector.

contravariant basis vector See also **tangent basis vector**. Given a position vector $\mathbf{x} = x^0\hat{\mathbf{x}} + x^1\hat{\mathbf{y}} + x^2\hat{\mathbf{z}}$ and curvilinear coordinate system $\xi^i(x^i)$, then the contravariant basis vectors are usually denoted $\mathbf{e}^i$ (with a superscript) given by $\mathbf{e}^i = \frac{\partial \xi^i}{\partial \mathbf{x}} = \nabla \xi^i$. Note that while widespread, the terminology is poor because if one uses the convention that only vector components can be covariant or contravariant, then a "contravariant basis vector" can be represented covariantly or contravariantly.

convection-diffusion model A transport model for plasma quantities' responses to perturbations using $\frac{\partial f}{\partial t} + \boldsymbol{\nabla} \cdot \Gamma(f, g, \ldots) = S_f$ where f is the plasma parameter of interest, $\Gamma(f, g, \ldots)$ is the flux associated with f dependent on all plasma parameters $f, g, \ldots$, and S_f is a source or sink of f.

coordinate frame A coordinate system made up of coordinate axes for space and time.

Coriolis effect See **Coriolis force**.

Coriolis force A force that comes from being in a rotating non-inertial frame. It is usually denoted for an angular velocity $\boldsymbol{\omega}$ as $-2m\boldsymbol{\omega} \times \frac{\mathrm{d}\mathbf{r}}{\mathrm{d}t}$ with the differentiation occuring in the rotating frame coordinates, that is, $\frac{\mathrm{d}\mathbf{r}}{\mathrm{d}t} = \mathbf{v}$ is the $\mathbf{v}$ in the rotating frame.

Coulomb collison A collision where the Coulomb force governs the behavior of the collision.

c

Coulomb explosion When a laser ionizes and accelerates most of the electrons off of atoms and the remaining positively charged ions strongly repulse each other, the ions "explode" away from each other.

Coulomb logarithm Usually refers to $\ln \Lambda$ where Λ is the **plasma parameter**. This logarithm shows up when doing Coulomb collision calculations.

coupling parameter For plasmas, this is the ratio of the electrical energy due to the Couloumb interaction over the thermal energy, $E_C/(k_BT) = \frac{e^2}{4\pi\epsilon_0 k_B T \langle a \rangle}$ with $\langle a \rangle = n^{-1/3}$. Note that this parameter is usually denoted Γ and is related to the **plasma parameter** by $\Gamma \sim \Lambda^{-2/3}$. For most fusion applications, the plasmas are very weakly coupled and so $\Gamma \ll 1$.

covariant When referring to a vector $\mathbf{v}$'s specified components, v_i is covariant when it transforms under change of coordinates as $\tilde{v}_i = \frac{\partial x^j}{\partial \xi^i} v_j$ where x^i are the original vector basis and ξ^i is the new coordinate basis. Covariant indices in **Einstein summation notation** are denoted with a subscript. The are called covariant because they vary with scale changes (so when going from millimeters with component v_i to meters with component $\tilde{v}_i$, we have $\tilde{v}_i = 1000 v_i$ just as meters are 1000 times a millimeter). In general, a component of a tensor is called covariant if that component transforms as above for a coordinate change. Many texts consider vectors to be arrays of numbers in which case they may refer to covariant vectors.

covariant basis vector See also **tangent-reciprocal basis vector**. Given a position vector $\mathbf{x} = x^0\hat{\mathbf{x}} + x^1\hat{\mathbf{y}} + x^2\hat{\mathbf{z}}$ and curvilinear coordinate system $\xi^i(x^i)$, then the covariant basis vectors are usually denoted $\mathbf{e}_i$ (with a subscript) given by $\mathbf{e}_i = \frac{\partial \mathbf{x}}{\partial \xi^i}$. Note that while widespread, the terminology is poor because a covariant basis vector is actually most easily represented with contravariant components and if one uses the convention that only vector components can be covariant or contravariant, then a "covariant basis vector" can be represented covariantly or contravariantly.

cp Short for compare. See **cf**.

crystal A solid substance that has an ordered pattern in every direction.

CTH See **Compact Toroidal Hybrid**.

current channel This typically refers to a small region around a rational surface $|x| < x_*$ (where x is distance from the rational surface and $x_* = |\omega/(k'_\parallel v_{\mathrm{th}_e})|$ with $k'_\parallel$ the derivative of the wavenumber parallel to the magnetic field and v_{th_e} the electron **thermal velocity**) where the electron contribution to the parallel current is large. More generically, a small region containing an amount of current that needs to be modeled.

curvature Curvature is a measure of how curved (how silar a curve is locally to a circle) a trajectory is. It is used in the **Frenet-Serret frame**, and is projected into components for the **Darboux frame**, where curvature due to the surface constraint may not be of interest.

curvature drift This is the drift of a single particle in a guiding magnetic field due to the curvature of the magnetic field itself. It can be thought of as the centrifugal force acting on the particle traveling along a curved magnetic field line. The most general form is given by $\frac{v_\parallel^2}{\Omega B}(\mathbf{B} \times \boldsymbol{\kappa})$ where $v_\parallel$ is the velocity parallel to the magnetic field, $\mathbf{B}$ is the magnetic field, $B = |\mathbf{B}|$ is the magnetic field intensity, Ω is the **cyclotron frequency**, and $\boldsymbol{\kappa}$ is the **magnetic field curvature**. It is also given by $\dfrac{mv_\parallel^2}{qB^2}\dfrac{\mathbf{R} \times \mathbf{B}}{R^2}$ for a circular magnetic field where R is the **radius of curvature** (it points toward the center of the circle) and m is the mass and q the electric charge of the particle.

cutoff frequency The frequency above which a plasma wave ceases to propagate and usually becomes an **evanescent wave**.

cyclotron frequency This is the frequency at which a particle with constant velocity would gyrate in a uniform magnetic field perpendicular to the constant velocity. This also works for particles gyrating around magnetic field lines. It is different for different charges and masses and is given by $\Omega_s = \frac{q_s B}{m_s}$ (SI) or $\Omega_s = \frac{q_s B}{m_s c}$ (Gaussian) where q_s is the charge of the species particle s and m_s is the mass of that particle. Note that one applies it for varying magnetic fields, and imagine that the particle's cyclotron frequency is changing as it follows the magnetic field lines.

cyclotron radius For a particle gyrating around a magnetic field line, this is the radius at which it is gyrating. It is given by $\rho = \frac{v_{\perp s}}{\Omega_s} \approx \frac{v_{\mathrm{th}_s}}{\Omega_s}$ where s is a species label. Here $v_\perp$ is the velocity perpendicular to the magnetic field direction, and v_{th} is the **thermal speed** of the particle species.

cyclotron resonance This is where particles resonate at their cyclotron frequency. This is a way to get energy to the particles and how **ICRF** and **ECRF** work.

D d

Darboux coordinates See **canonical coordinates**.

Darboux frame See also **Frenet-Serret frame**. The Darboux frame is a frame that parameterizes a particle's (or magnetic field line's) trajectory along a surface. It is different from the **Frenet-Serret frame** because the particle is constrained to a surface. Both frames use a **tangent vector**, **normal vector**, and **binormal vector**. The normal vector and the binormal vector are different from the Frenet-Serret frame's because of the existence of a normal vector due to the surface constraint. One then uses the **normal curvature** and **geodesic curvature**, and normal or **geodesic torsion**.

DAx See **double-axis** state.

Debye length Electrons and ions in a plasma tend to shield the effects of distant charges by cancelling charge (similar to how the interior electrons in an atom shield most of the nuclear charge from the outermost electron). The Debye length is the length below which charge shielding is no longer a good assumption and so charge distribution at the microscopic level becomes extremely important. Usually denoted $\lambda_D = \sqrt{\frac{\epsilon_0 k_B}{\sum_s \frac{q_s n_s}{T_s}}} \approx \sqrt{\frac{\epsilon_0 k_B T_e}{n_e e^2}}$ where the s is a species label and the ion species terms are dropped for the last term (so only electron contributions, as they usually are). This is named after Peter Debye.

Debye sheath This is the region between the surface of a material and a plasma, where charge builds up to form an interface. Typically the electrons accelerate to the material surface and arrive first due to their low mass, and so the ions attempt to screen out the potential. The typical length of such a sheath is the Debye length.

Debye sphere This is $(4/3)\pi\lambda_D^3$ (with λ_D the **Debye length**) and is the region for outside of which charge shielding occurs so that microscopic effects within a Debye sphere can be ignored outside of the sphere. That is outside of the Debye sphere the charges inside the sphere are screened. Note that the factor in front of λ_D^3 is sometimes omitted (then a "Debye cube") for calculations.

degree of freedom This is the number of parameters that can be varied independently, and so completely determine the state of a system.

degree of ionization This is the percentage of atoms in a plasma/gas mixture that are ionized. Generally, a plasma/gas with low degree of ionization is a cold plasma, but it is possible for a low degree of ionization plasma to have ions that are hot (i.e., the ions that are ionized are very ionized with most of their electrons stripped from them).

d

del See **nabla**.

Delta-prime It is denoted Δ' and is a parameter used to determine if a **tearing mode** or **twisting mode** is stable. In the zero β (**plasma beta**) case, it represents the total current in a boundary layer near a **rational surface**. For **tearing/twisting modes**, $\Delta' > \Delta_{\text{critical}}$ indicates stability for some Δ_{critical} value. Δ' is the difference in values across the rational surface of some quantity corresponding to the eigenfunction, (for example, $\frac{1}{B_r}\frac{\partial B_r}{\partial r}$). Note that often for modes with **poloidal mode number** $m = 1$, Δ' is said to be large (meaning for the width of the boundary layer w that $\Delta' w \gg 1$) and for $m \neq 1$, Δ' is said to be small (meaning $\Delta' w \ll 1$).

dense plasma focus A method to create a possible plasma energy device using both the **pinch effect** and a discharge current across the plasma.

density limit A limit on the number density above which the plasma becomes unstable. These can be due to a variety of effects. For tokamaks, a well-known limit is the **Greenwald limit**.

derivative Given a function $f(x)$, after differentiating f (that is using **differentiation**) one has the derivative of f, called $\frac{\mathrm{d}f}{\mathrm{d}x}$ or f'. One can take more than one derivative, in which case one has the nth derivative if one differentiates the function f, n times.

deuteron This is the nucleus of the isotope of hydrogen with 1 neutron, sometimes deonted D or $^2_1$H.

DIA See **Direct Interaction Approximation**.

diamagnetic current This is current due to pressure gradients, and is called a diamagnetic current because it generally "creates" a magnetic field opposing the externally applied one. See **diamagnetism**. It's value is $\mathbf{J} = \dfrac{\mathbf{B} \times \nabla p}{B^2}$ (SI) or $\mathbf{J} = \dfrac{c\mathbf{B} \times \nabla p}{B^2}$ (Gaussian). One notes that this is a portion of the perpendicular (to the magnetic field) current $\mathbf{J}_\perp$.

diamagnetic drift This is a drift of particles due to a pressure gradient. It is not a true single-particle effect but is caused by more particles going in one direction than another due to a pressure gradient. The value of the drifft velocity is $\mathbf{v}_D = \dfrac{B \times \nabla p}{qnB^2}$ (SI) or $\mathbf{v}_D = \dfrac{c\mathbf{B} \times \nabla p}{\sqrt{qnB^2}}$ (Gaussian). This is related to the **diamagnetic current**. See figure 4.

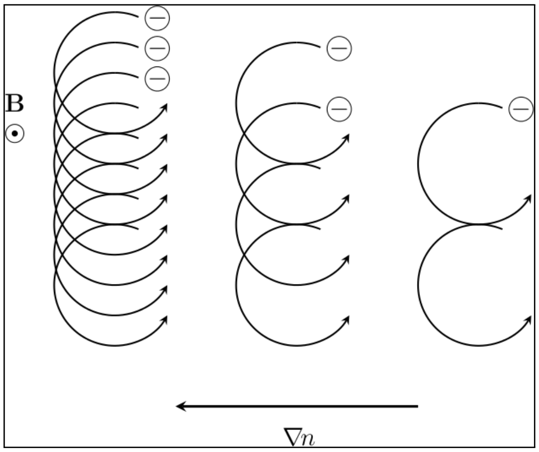

Figure 4: This shows a density gradient in electrons and how it can contribute to a mean flow, called a diamagnetic flow. Note in this picture, the diamagnetic flow will be upward, due to more particles flowing upward than downward.

diamagnetism This is the phenomenon of a material in a magnetic field developing a magnetization that creates a magnetic field that opposes the external magnetic field. A material in which this is the most important magnetic effect is called a diamagnetic material, which can be known by having a negative magnetic susceptibility, χ_m.

dielectric A material that is electrically insulating that can be polarized by an externally applied electric field.

dielectric constant See **permittivity of free space**.

dielectric tensor This is a tensor quantity that yields information on how a dielectric responds to an externally applied field. Plasmas can be modelled as dielectrics, and so the tensor yields information of how a plasma responds to an electric field.

differentiation A mathematical process that yields the difference in a function when its argument is changed by a small amount. Many notations are used including **Lagrange's prime notation**, **Euler's notation**, and primarily **Leibniz notation**, although for time derivatives **Newton's dot notation** is sometimes employed. It is defined as $\frac{\mathrm{d}f}{\mathrm{d}x} = \lim_{h\to 0} \frac{f(x+h)-f(x)}{h}$.

diffusion This is the movement of particles from one region to another.

diffusion constant This is a measure of the movement of particles from one region to another. It is usually designated D with units of m^2/s, which can be roughly though of as the distance traveled Δx in a time Δt in a random walk process so that $D \approx \frac{(\Delta x)^2}{\Delta t}$.

Direct Interaction Approximation A statistical model for **turbulence** developed by Kraichnan. It is more complicated than **EDQNM**, but derives the temporal response function, but still closes its moments by saying fourth-order and higher moments are zero.

disk flux A **poloidal flux** where the poloidal surface is a circle in the $Z = 0$ plane (in cylindrical coordinates) centered around the geometric axis with some radius set into the torus. See figure 5.

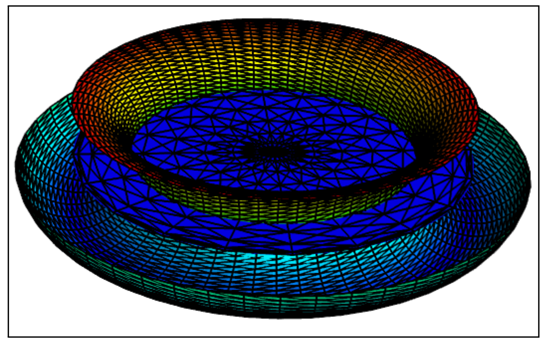

Figure 5: The blue disk through the cut-open torus represents a possible poloidal flux surface. This configuration is a poloidal disk flux.

dispersion The property of a wave moving through a material where different wavelengths have different propagation speeds.

dispersion relation This is a mathematical relationship between the angular frequency, ω, and the wave number, k, given by some function of k, $f(k)$ given by $\omega(k) = f(k)$. This relation yields information such as the **group velocity** and **phase velocity**.

disruption An instability in a plasma which grows and causes the plasma to rapidly deposit its energy into the confinement vessel terminating the plasma.

distribution function A function that gives the number of particles per unit volume in phase space. In plasma physics usually denoted as $f = f(\mathbf{x}, \mathbf{v}, t)$.

divergence This is a vector operator, that relates whether an area is a source or sink of some quantity, and how much of a source or sink. Usually denoted with the **del** operator ($\boldsymbol{\nabla}\cdot$) or div. So for vector field $\mathbf{A}$, $\boldsymbol{\nabla}\cdot\mathbf{A} = \operatorname{div}\mathbf{A}$.

divertor A component of a confinement device that the magnetic field diverts charged ions at the edge of the plasma into. This is used so that the edge ions do not hit the inner surface of the confinement vessel all over the place.

Doppler effect This is an effect where a source frequency and the observed frequency of a wave changes depending on the motion of the source and observer relative to the speed of the wave in the medium. If c is the speed of the wave in the medium, and we assume the source moves away from the observer, then if the source moves at velocity v_s with respect to the medium, and the observer moves at velocity v_o with respect to the medium then the observed frequency ν_o is related to the source frequency ν_s by $\nu_o = \dfrac{c+v_s}{c-v_o}\nu_s$. The signs change when the source moves toward the observer. Named for Christian Doppler.

dot notation See **Newton's dot notation**.

double-axis An **RFP** state that occurs in the **QSH** regime where a second helical magnetic axis forms asssociated with the QSH helical mode.

drift frequency This is the central frequency for fluctuations in the plasma. For $\mathbf{k}$ being a wave vector characterizing fluctuations, the drift frequency ω_* is given by $\omega_* = \mathbf{k}\cdot\mathbf{V}_d = \mathbf{k}\cdot\frac{1}{mn\Omega}\hat{\mathbf{b}}\times\nabla p = \mathbf{k}\cdot\frac{\mathbf{B}\times\nabla p}{qnB^2}$. where $\mathbf{V}_d$ is the **diamagnetic drift**.

drift instability Drift instabilities generically refer to instabilities due to **drift motion** of the plasma. A canonical example is due to a small lack of adiabaticity in the electron particle number density. That is, $\frac{\widetilde{n_e}}{n_{e0}} = (1-i\Delta)\frac{e\widetilde{\Phi}}{T_e}$ with $\Delta = \frac{2m_e}{m_i}\frac{\omega_*}{\Omega_i^2\tau_{ei}}\left(\frac{k_\perp}{k_\parallel}\right)^2 \ll 1$ where m_e, m_i are the electron and ion masses, ω_* is the **drift frequency**, Ω_i is the ion **cyclotron frequency**, τ_{ei} is the electron-ion **collision time**, and $k_\parallel$ and $k_\perp$ are the wavenumbers parallel and perpendicular to the magnetic field. Note that if $\Delta = 0$ then the electrons are adiabatic. See also the **Hasegawa-Mima equation**.

drift motion Particles that follow magnetic field lines have a **guiding center** which can drift off of the original magnetic field line if the magnetic field is nonuniform. This motion of the particles is called drift motion.

drift order An ordering of velocities in kinetic theory such that $\frac{V_E}{v_{\text{th}}} \sim \delta$ where V_E is the $\mathbf{E}\times\mathbf{B}$ drift, v_{th} is the thermal velocity and δ is a **magnetization** parameter. Thus, the fluid velocity V_E is "small" compared to the thermal velocity of particles. This leads to the **drift kinetic equation**.

drift velocity The typical velocity at which a particle's **guiding center** drifts when **drift motion** occurs. It is given by $\mathbf{v}_D = \mathbf{V}_E + \frac{1}{\Omega}\hat{\mathbf{b}}\times\left(\frac{\mu}{m}\nabla B + v_\parallel^2\boldsymbol{\kappa} + v_\parallel\frac{\partial\hat{\mathbf{b}}}{\partial t}\right)$ where $\mathbf{V}_E$ is the $\mathbf{E}\times\mathbf{B}$ drift, $\hat{\mathbf{b}} = \frac{\mathbf{B}}{|\mathbf{B}|}$, B is the magnetic field intensity, $v_\parallel = \mathbf{v}\cdot\hat{\mathbf{b}}$, Ω is the **cyclotron frequency** and $\boldsymbol{\kappa} = \hat{\mathbf{b}}\cdot\nabla\hat{\mathbf{b}}$ is the **magnetic field curvature** corresponding to the **curvature drift**.

drift waves These are plasma oscillaitons/fluctations which are primarily electrostatic and usually satisfy $k_\parallel v_{\text{th}_i} \ll \omega_* \sim \omega \ll k_\parallel v_{\text{th}_e}$ with ω_* the **drift frequency**, ω the frequency of the oscillation, $k_\parallel$ the wave vector along the magnetic field and v_{th} being the thermal velocity for ions or electrons.

drift-kinetic equation A kinetic equation that describes **magnetized plasmas** by suppressing details of the short **gyroradius** scale. That is, it is averged over the gyro-scale. An approximate form is given by

$$\frac{\partial\bar{f}}{\partial t} + (\mathbf{v}_\parallel + \mathbf{v}_D)\cdot\nabla\bar{f} + \left[e\frac{\partial\Phi}{\partial t} + \mu\frac{\partial B}{\partial t} - e\mathbf{v}_\parallel\cdot\frac{\partial\mathbf{A}}{\partial t}\right]\frac{\partial\bar{f}}{\partial U} = C$$

where $\bar{f}$ represents the gyroaveraged (over gyrophase) distribution function, $\mathbf{v}_\parallel = \mathbf{v}\cdot\frac{\mathbf{B}}{|\mathbf{B}|}$, $\mathbf{v}_D$ is the **drift velocity**, Φ is the electric potential, $B = |\mathbf{B}|$, μ is the **magnetic moment**, $\mathbf{A}$ is the **vector potential**, $U = \frac{mv_\parallel^2}{2} + e\Phi + \mu B$ is the total guiding-center energy, and C is the **collision operator**. See *Plasma Confinement* by Hazeltine and Meiss Chapter 4.2.

dusty plasma A plasma containing particles of solid matter (typically nm to mm in size) which are electrically charged. Also called **complex plasma** or, when strongly coupled, a **plasma crystal**.

dyad A type of product between two vectors that is not commutative and produces second rank **tensors**.

E e

e

$\mathbf{E} \times \mathbf{B}$ drift This is a single particle drift due to an electric field crossed with a magnetic field. Note this is a drift that does not depend on the sign of the charge. $v_D = \dfrac{\mathbf{E} \times \mathbf{B}}{B^2}$ (SI) or $v_D = \dfrac{c\,\mathbf{E} \times \mathbf{B}}{B^2}$ (Gaussian).

e.g. Latin. Short for *exempli gratia*. This translates as "for example".

EBW Stands for **electron Bernstein wave**. See **Bernstein wave**.

ECRF Electron Cyclotron Range of Frequencies. A mechanism to heat up plasmas by using the electron **cyclotron frequency**.

Eddy-Damped Quasinormal Markovian Closure Often abbreviated **EDQNM**. This is a model that extracts quantities of interest for **turbulence** from the statistical properties of the system. It involves using the **quasinormal closure**. The Markovian part of the approximation involves evaluating a fluctuating quantity at time t instead of integrating it over a range of time t'.

edge localized mode Shortened to **ELM**. A plasma instability near the edge of the plasma in an **H-mode** plasma due to a relaxation of a transport barrier from the **L-mode** to **H-mode** transistion. That is the **H-mode** builds up **number density** and **temperature** gradients, an ELM occurs which removes sharp gradients (leading to **sawteeth**). There are different types of ELMs (the type number being from order of discovery). (Type I) ELM repetition frequency increases with heating power, isolated sharp bursts of D_α (deuterium alpha line in spectroscopy) often without a magnetic precursor and occur far above L-H mode transition. (Type II) The repetition frequency is faster than Type I but the D_α signal decreases. These are usually smaller and do not affect confinenment much. (Type III) ELM repetition frequency decreases with heating power with a magnetic precursor and is usually near the L-H transition.

EDQNM See **Eddy-Damped Quasinormal Markovian Closure**.

eigenfunction Given some operator D acting on a **field**, when D acts on a particular x in the field that D acts on (so x is appropriate for D), then if D acting on x is symbolized $D \circ x$, we have ω as an **eigenvalue** and x an **eigenfunction** when $D \circ x = \omega x$ with ω a **scalar**. Usually when the field is a **Hilbert space** or if the x has an infinite number of entries, then it is called an **eigenfunction** rather than an **eigenvector**.

eigenvalue Given some operator D acting on a **field**, when D acts on a particular x in the field D acts on, then if D acting on x is symbolized $D \circ x$, we have ω as an **eigenvalue** and x an **eigenvector** or **eigenfunction** when $D \circ x = \omega x$ with ω a **scalar**.

eigenvector Given some operator D acting on a **vector field**, when D acts on x, with x in the vector field D acts on, then if D acting on x is symbolized $D \circ x$, we have ω as an **eigenvalue** and x is an eigenvector when $D \circ x = \omega x$ with ω a **scalar**. Note that as it is acting on a vector field, and because x has a finite number of elements, it is usually called an **eigenvector** rather than an **eigenfunction**.

Einstein summation notation A notation where a repeated index implies that the repeated index should be summed. For example, suppose x^i is x, y, z for $i = 1, 2, 3$, then $x^i x_i$ means $\displaystyle\sum_{i=1}^{3} x^i x_i = x^2 + y^2 + z^2$.

elastic modulus See **Young's modulus**.

electric consant See **permittivity of free space**.

electric dipole moment This is a measure of the separation of positive and negative charges. For two oppositely charged particles, it is given by $\mathbf{p} = q\mathbf{d}$ where $\mathbf{p}$ is the electric dipole moment, $\mathbf{d}$ is the displacement pointing from negative to postive, and q is the charge of the positive charge.

electric potential See **electric scalar potential**.

electric scalar potential A **scalar potential** for the electric field $\mathbf{E}$. It is also called a voltage or **electric potential**. Usually denoted V or ϕ, it is defined through $-\nabla\phi = \mathbf{E}$.

electric susceptibility This is a dimensionless proportionality constant that indicates the degree of **polarization** of a material due to an applied electric field. Usually denoted χ_e (or just χ if there is no chance of confusion with the **magnetic susceptibility**), it is defined by $\mathbf{P} = \chi_e \epsilon_0 \mathbf{E}$ with $\mathbf{P}$ the polarization density, ϵ_0 the **permittivity of free space**, and $\mathbf{E}$ the electric field.

electron adiabaticity This means that electrons respond adiabatically and so remain close to a Maxwell-Boltzmann equilibrium, i.e., $n_e \exp\left(-\frac{e\Phi}{k_B T_e}\right) \simeq$ constant, or equivalently, $\frac{\widetilde{n}_e}{n_{e0}} = \frac{e\widetilde{\Phi}}{k_B T_e}$ where n_e is electron number density, e is the elementary charge, Φ is the electric potential and k_B is the Boltzmann constant and T_e is electron temperature. Here, $\widetilde{r}$ for a quantity r indicates the first order linearization term and r_0 indicates the zeroth order or equilibrium term for the quantity r. Yet another condition for electron adiabaticity is that $k_\parallel v_{\text{th}_e} \gg \omega$ for $k_\parallel$ the wave vector along the magnetic field, v_{th_e} the electron thermal velocity, and ω the frequency of the electrostatic perturbation. For models which have electrons satisfying this relationship, the electrons are called adiabatic.

electron Bernstein Wave See **Bernstein wave**.

electron cyclotron heating By applying a frequency near the electron **cyclotron frequency**, it excites the electrons in the plasma which thermalize with the other electrons and ions.

electron cyclotron wave A plasma wave at the electron **cyclotron frequency**.

electron gas A model where electrons are completely detached from the ions and there are no electron-electron interactions. In additon, ion mass is neglected (that is, ions are set to be stationary) by setting it to ∞.

electron temperature gradient Usually refers to the instability associated with having too steep an electron tempearture gradient (along the **minor axis**). Called an **ETG**.

electrostatic confinement Confinement of a plasma without magnetic fields.

ellipsoid A three-dimensional figure that is defined by the equation $a_1x^2+a_2y^2+a_3z^2+a_4xy+a_5xz+a_6yz = r^2$ for some value of r. Figure 6 shows a particular ellipsoid. Note that a_4, a_5, a_6 tilt the ellipsoid.

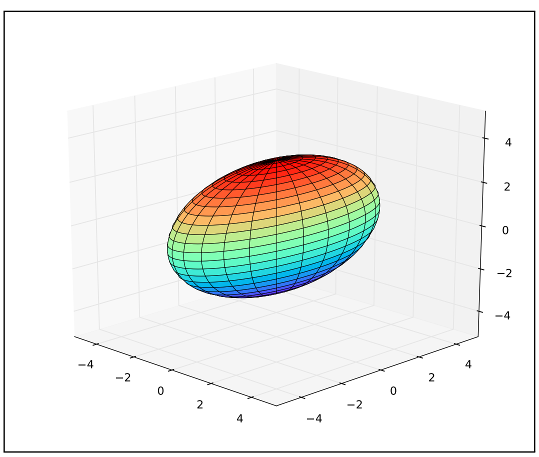

Figure 6: An ellipsoid with $a_1 = \frac{1}{2^2}, a_2 = \frac{1}{5^2}, a_3 = \frac{1}{3^2}$ corresponding to half-lengths of the axes of 2 in the x-direction, 5 in the y-direction, and 3 in the z-direction for the extent of the ellipsoid.

ellipticitiy This is a measure of how elliptic (that is, how far it diverges from circular cross section) the magnetic surface structure of the plasma. It is usually given by $\kappa \equiv \frac{Z_{\max}-Z_{\min}}{R_{\max}-R_{\min}}$ where max and min refer to the maximum R or Z value on the **LCFS**. Note that $a = (R_{\max} - R_{\min})/2$ is often defined as the **plasma minor radius** so that $\kappa = (Z_{\max} - Z_{\min})/(2a)$.

e

ELM See **edge localized mode**.

elongation This refers to elongating a circular cross-section for plasma magnetic surfaces into an elliptical shape. This is usually done for better plasma performance. See also **ellipticity** and **triangularity**.

energy An abstract concept that is invariant in a number of situations. One way of viewing energy, is as a measure of a motion and the ability to move things. It is difficult to give an idea of what all energy is, but different forms are accessible enough, such as **kinetic energy**, heat energy, magnetic energy, electrical energy and **potential energy**, for example. Energy is measured in joules (SI) or ergs (Gaussian), which have dimensions of mass^{2}length^2/time^2.

energy confinement time This time (usually dentoted τ_E or τ_e) is given by the global plasma energy divided by the net power required to maintain the steady state (subtracting off the unavoidable energy losses),$\tau_E = U/(W_{\text{in}} - W_{\text{loss}})$ where W_{in} is the net rate of energy input, W_{loss} is the unavoidable energy loss rate (such as radiation), and U is the global plasma energy. In **FRCs** and many other applications, one often uses $\tau_E = U/W_{\text{in}}$ instead since energy losses are unavoidable.

energy principle In **MHD**, this principle states that if a perturbation makes the potential energy negative, then the system is unstable.

enstrophy This is the integral of the square of the vorticity. $\mathcal{E} = \frac{1}{2}\int_S \mathrm{d}S\ |\boldsymbol{\omega}|^2 = \frac{1}{2}\int_S \mathrm{d}S\ |\boldsymbol{\nabla}\times\mathbf{u}|^2$ where $\boldsymbol{\omega} = \boldsymbol{\nabla}\times\mathbf{u}$ is the vorticity, S is the area to be integrated over, and $\mathbf{u}$ is the flow velocity. It is related to the kinetic energy in the flow corresponding to dissipation effects in the fluid.

entropy A measure of how many ways a system can be arranged in. *Not* a measure of disorder. It is often used as a measure of disorder, though. [It is not a measure of disorder in the physical sense because of the following example. Consider a suitcase that needs to be packed. If one puts nicely folded clothing into it, but so it is only very shallowly filled, then one would like to say that the system is ordered and has a lower "entropy". Indeed, there are many more ways for the clothing to be in a disordered state, and so the disordered state has higher "entropy." However, suppose instead you filled the suitcase full with nicely folded clothes. Now there are many ways to do this, but if e

you just throw the clothes in, there are only a few ways as the suitcase will be unable to close. Hence the ordered case has more "entropy." This is analogous to some crystal systems.]

equation of motion In dynamical situations, it turns out that only second degree differential equations are required to give the full trajectories of particles. That is, differential equations only involving up to the second derivative of position. The equation of motion, is then this differential equation. Note if there are multiple dimensions, then the equations of motion may be coupled. An example for freefall is $m\ddot{x} = mg$ where m is the mass of a particle, $\ddot{x}$ is the acceleration, and g is the gravitational constant.

ergodic This means filling completely. For example, a particle trajectory ergodically filling in a surface means that it comes arbitrarily close to any point on the surface. This process may take an infinite amount of time, and typically also implies a degree of random-looking behavior. More typically, one refers to ergodically filling a volume rather than a surface.

ergodic regime In this regime, a magnetic field line will ergodically cover a surface whose safety factor is irrational.

error field For a tokamak, this is the magnetic field due to imperfections in the magnet/confinement vessel. That is, the vessel and magnetic fields are not actually axisymmetric and so have "errors" due to this breaking of axisymmetry.

et al. Latin. Short for *et alii*, *et alia*, or *et alibi*. This translates as "and others". Should be used for people rather than etc.

et seq. Latin. Short for *et sequentes* or *et sequentia*. This translates as "and the following".

ETB See **external transport barrier**.

ETG See **electron temperature gradient**.

Euler's notation The notation of a derivative with respect to x as a D_x.

Euler's theorem on homogeneous functions For a **homogeneous function** of degree k [i.e., $S(\alpha x_1, \alpha x_2, \ldots, \alpha x_n) = \alpha^k S(x_1, x_2, \ldots, x_n)$], this theorem states $\sum_i x_i \frac{\partial S(x_1,\ldots,x_n)}{\partial x_i} = kS(x_1,\ldots,x_n)$. The proof is simple, with the identity $\frac{\partial S(\alpha \mathbf{x})}{\partial \alpha} = \frac{\partial}{\partial \alpha}\left(\alpha^k S(\mathbf{x})\right) = k\alpha^{k-1}S(\mathbf{x})$ with the shorthand of $\mathbf{x}$ for all the x_i. Then we have $\frac{\partial S(\alpha \mathbf{x})}{\partial \alpha} = \frac{\partial S(\alpha \mathbf{x})}{\partial(\alpha \mathbf{x})} \cdot \frac{\partial(\alpha \mathbf{x})}{\partial \alpha} = \mathbf{x} \cdot \frac{\partial S(\alpha \mathbf{x})}{\partial(\alpha \mathbf{x})}$ which says $\sum_i x_i \frac{\partial S(\alpha x_1,\ldots,\alpha x_n))}{\partial(\alpha x_i)} = k\alpha^{k-1}S(\alpha x_1,\ldots,\alpha x_n)$ which for $\alpha = 1$ yields $\sum_i x_i \frac{\partial S(x_1,\ldots,x_n)}{\partial x_i} = kS(x_1,\ldots,x_n)$.

Euler-Lagrange equations These are the equations giving the stationary functions of a functional (similar to a **stationary point** for a function). In Lagrangian mechanics, the **action**, $S = \int_a^b L\,\mathrm{d}t$ where L is the **Lagrangian** has its stationary functions as the trajectories of particles. For i coordinates, we have $\frac{\mathrm{d}}{\mathrm{d}t}\left(\frac{\partial L}{\partial \dot{q}_i}\right) - \frac{\partial L}{\partial q_i} = 0$, where the q_i are **generalized coordinates**.

Eulerian coordinates These coordinates give the **flow velocity** of a system as a function of position and time. So $\mathbf{v} = \mathbf{v}(\mathbf{x}, t)$ for flow velocity $\mathbf{v}$. This is to be compared to the **Lagrangian coordinates** which instead give flow velocity by looking at how parcels of material move in time. The connection between these two systems is $\mathbf{v}(\mathbf{X}(\mathbf{x}_0, t), t) = \frac{\partial \mathbf{X}(\mathbf{x}_0,t)}{\partial t}$ (see **Lagrangian coordinates** for notation).

evanescent wave A wave that decays exponentially as it goes through a surface normally (perpendicular to the surface). It does not put an energy flux into the medium it seems to be propagating into.

exact differential See **perfect differential**

external transport barrier Usually shortened to **ETB**. This is an area of steep gradients (in temperature, number density, and/or pressure) at the edge of a toroidal plasma (in a **tokamak**, **stellarator**, or **RFP**, for example), usually when operating in **H-mode**. Typically, these steep gradients lead to improved energy confinement, and so better transport characteristics for a fusion reactor.

extraordinary wave One of the types of waves (or modes) that can be excited in a plasma. (In ordinary optics it would actually be the ordinary wave).

F f

facula For solar facula, bright spots on the sun formed by high concentrations of magnetic field.

Fadeeva function The Fadeeva function is related to the **plasma dispersion function** with the $Z(\zeta) = i\sqrt{\pi}w(\zeta)$ where $w(\zeta)$ is the Fadeeva function and $Z(\zeta)$ the plasma dispersion function used by Freid and Conte.

Faraday rotation The rotation of the polarization of a light wave when traveling parallel to a magnetic field. The amount of rotation can determine the magnetic field strength.

fast Alvén wave See **magnetoacoustic wave**.

fast ions Ions with a temperature much greater than the characteristic temperature of the ions in the plasma.

ferromagnetism This is the mechanism by which some materials form permanent magnets. May also refer to magnetic fields due to ferromagnetic materials.

field line curvature See **magnetic curvature**.

Field-Reversed Configuration (**FRC**). This is a possible fusion confinement device. It has very little toroidal field, and is a **compact toroid**. It is a produced in **theta pinch** device.

filament See **blob**.

finite Larmor radius FLR. For many theories, the **Larmor radius** is considered negligible. If effects of the actual finiteness of the Larmor radius come into effect then they refer to FLR.

first law of thermodynamics The total energy of an **isolated system** is conserved. Where U is the energy, it is often stated as $\mathrm{d}U = \delta Q - p\,\mathrm{d}V$ with T the temperature in an absolute scale (i.e., 0 is **absolute zero**) S is the entropy, Q is the heat, p is the pressure, and V is the volume. The δ is used to stress that heat Q is not a perfect differential.

fishbones Oscillations due to **neutral beam injection**. It comes from the $m = 1$ **internal kink mode**. The shape of the characteristic magnetic fluctuation symbol yields its name.

flow velocity This is the average **velocity** of a **fluid** through some region, not to be confused with the velocities of the particles making up the fluid.

FLR See **finite Larmor radius**

fluid A material or medium that can change its shape when put in a different container. **Liquids** and **gases** both are fluids, while plasmas often are.

flute instability A type of plasma **interchange instability** where the perturbation is parallel to the magnetic field. In a cylinder, this makes a fluted shape.

flux There are two definitions of flux. The second definition applies for magnetic and electric fields. (1) In transport, flux measures how much of some quantity is flowing through some surface per second. For example, with the flux of Q (with dimension of Q being $[Q]$) measured in dimensions $[Q]/((\text{time})(\text{area}))$. (2) In general, the flux of vector quantity $\mathbf{Q}$ (denoted Φ) is given by $\Phi = \iint_S \mathbf{Q} \cdot \mathrm{d}\mathbf{A}$ and so measures the density of the flow through a surface.

flux label A label for a particular **flux surface**. Can be used as part of a coordinate system. (The true full name would be **magnetic flux label**).

flux loss time In **FRCs**, the decay time (the time it takes to go down to $1/e$ of the initial value) of the poloidal flux Φ_P.

flux surface A surface that a single magnetic field line **ergodically** fills. (If the field line does not fill a surface, one may have a **flux volume**, or just a field line if the line meets itself.) (The true full name would be **magnetic flux surface**).

flux volume A volume filled **ergodically** by a single magnetic field line. (The true full name would be **magnetic flux volume**).

force Any "thing" that causes a change in an object's **momentum**. If this strikes you as **tautological** when in conjunction with **Newton's second law**, then you are correct, but don't worry about it too much. It has units of newtons (SI) or dynes (Gaussian) with dimensions of masslength/time^2.

force-free configuration In a plasma governed by $\mathbf{J} \times \mathbf{B} = \nabla p$ with $\mathbf{J}$, $\mathbf{B}$, and p the current density, magnetic field, and pressure, respectively, if $\mathbf{J} = A\mathbf{B}$ for some A then the configuration is called force-free.

force-free currents Currents that run parallel to the magnetic field and so are unaffected by the **Lorentz force**.

forced reconnection This refers to **magnetic reconnection** in the case where the region would normally be stable, but some small perturbation "forces" it to reconnect. In a tokamak, sense, if there is a (m, n) plasma mode that is stable, an applied magnetic perturbation causes it to reconnect.

f

f

Fourier dual Given $f(t)$ and the **Fourier transformation** $\tilde{f}(\omega)$, the variables t and ω are called Fourier duals.

Fourier transform This is a transformation of a function $f(t)$ to a new function that depends on a different varible, say ω. This is given by one of three forms depending on the definition employed. If the Fourier transform of $f(t)$ is denoted $\tilde{f}(\omega)$, then the three common definitions are

$$\tilde{f}(\omega) = \frac{1}{2\pi}\int_{-\infty}^{\infty} f(t)e^{-i\omega t}\,\mathrm{d}t$$
$$\tilde{f}(\omega) = \frac{1}{\sqrt{2\pi}}\int_{-\infty}^{\infty} f(t)e^{-i\omega t}\,\mathrm{d}t$$
$$\tilde{f}(\omega) = \int_{-\infty}^{\infty} f(t)e^{-i\omega t}\,\mathrm{d}t \quad .$$

So that the inverse Fourier transform, respectively is given by

$$f(t) = \int_{-\infty}^{\infty} \tilde{f}(\omega)e^{i\omega t}\,\mathrm{d}\omega$$
$$f(t) = \frac{1}{\sqrt{2\pi}}\int_{-\infty}^{\infty} \tilde{f}(\omega)e^{i\omega t}\,\mathrm{d}\omega$$
$$f(t) = \frac{1}{2\pi}\int_{-\infty}^{\infty} \tilde{f}(\omega)e^{i\omega t}\,\mathrm{d}\omega \quad .$$

Generally the second of the definitions above are employed as it is the most symmetric. Note sometimes a frequency variable is used instead of the angular frequency. In this case, $f(t)$ and $f(\nu)$ with $2\pi\nu = \omega$ the most common definition is then

$$\tilde{f}(\nu) = \int_{-\infty}^{\infty} f(t)e^{-2\pi i\nu t}\,\mathrm{d}t$$
$$f(t) = \int_{-\infty}^{\infty} \tilde{f}(\nu)e^{2\pi i\nu t}\,\mathrm{d}\nu \quad .$$

FRC See **Field-Reversed Configuration**.

free energy (1) In thermodynamics, this can mean **Gibbs free energy** or **Helmholtz free energy**. (2) In plasma physics, a source of "free energy" means that it is a potential driver of instability in the system. For example, pressure gradients can drive instabilities, and so the pressure gradient is a source of free energy.

Frenet-Serret frame See also **Darboux frame**. The Darboux frame is a frame that parameterizes a particle's (or magnetic field line's) trajectory along a surface. It is different from the **Darboux frame** because the particle is not constrained to a surface. Both frames use a **tangent vector**, **normal vector**, and **binormal vector**. One then measures the magnitude along each direction with the **curvature** and **torsion**.

Frozen Flux Theorem For **ideal MHD**, the total flux through a surface remains constant, even when moving. This ties a plasma to the magnetic field and vice versa.

full detachment This is when a plasma that hits a **divertor** plate is so cold, that is, it has very low energy because it has recombined into a gas, that there is not significant energy deposition into the divertor plate.

fully detached regime See **full detachment**.

fully ionized plasma A plasma where all neutrals have been ionized.

G g

Galilean transformation In nonrelativistic mechanics this gives how to change coordinates from an **inertial frame**, Σ to another inertial frame,Σ', with Σ' moving at a different but constant velocity relative to Σ. If Σ' is moving $-V\hat{\mathbf{x}} - V\hat{\mathbf{y}} + V\hat{\mathbf{z}}$ with respect to Σ (and we allow the axe coordinates and origin at time $t = 0$ to coincide) this yields that $x' = x + Vt$, $y' = y + Vt$, $z' = z + Vt$ and $t = t'$ as the Galilean transformation. It also leads to **Galilean velocity addition**. It is called Galilean after Galileo, not because he discovered it, but because it had no name before special relativity.

Galilean velocity addition If a coordinate frame Σ' is moving at velocity $\mathbf{V}$ with respect to coordinate frame Σ, then if an object is moving at velocity $\mathbf{v}$ in Σ it is moving at $\mathbf{v}' = \mathbf{v} - \mathbf{V}$ in Σ'. This rule for velocity addition is called Galilean after Galileo, who did not come it with originally, but had no name before special relativity.

gas A substance and state of matter that changes its shape to that of its container, and whose particles do not interact strongly with each other.

gas dynamic trap See **magnetic mirror**. Often abbreviated as **GDT**.

gauge-invariant A quantity that is not changed when one undergoes a change of **gauge**. This is equivalent in electrodynamics of saying the quantity doesn't change when $\mathbf{A} \to \mathbf{A} + \nabla f$ and $\Phi \to \Phi + \frac{\partial f}{\partial t}$ for some function f and $\mathbf{A}$ is the **magnetic vector potential** and Φ is the scalar **electrical potential**.

Gaussian system A **cgs** system of units for measuring electromagnetic phenomena. In this system, there is no electrical fundamental unit (like Ampère or Coulomb).

GDT A **gas dynamic trap**. See **magnetic mirror**.

generalized coordinates These are coordinates employed in **Lagrangian mechanics** that are not required to be cartesian or any given format. They simply are a coordinate system available in a system that leaves no free **degrees of freedom**. Note they do not have to have units of distance, as they can be angle coordinates, or anything else. They are generally given as q_i and $\dot{q}_i$.

generalized momenta These are "momenta" p_i that are **canonically conjugate** to some generalized coordinate q_i. They are called momenta because for q_j being a distance, it can corresond to normal momentum, but often this generalized momenta differs from the "classical" momentum one calculates from **Newton's second law**.

geodesic A path that is the "shortest" with some **metric**. In 3D space, a straight line is a geodesic, while great circles are geodesics on surfaces of spheres.

geodesic curvature Geodesic curvature is used with the **Darboux frame**. This is the curvature of the trajectory due to the particle path chosen on the constraining surface. For a **geodesic** path, the geodesic curvature is zero.

geodesic torsion This is a name for the **torsion**-like term in the **Darboux frame**. Sometimes it is called the **normal torsion**, as well. It is different from the **Frenet-Serret frame** torsion.

geometric axis In a toroidal geometry, this is the Z-axis as shown in Figure 7.

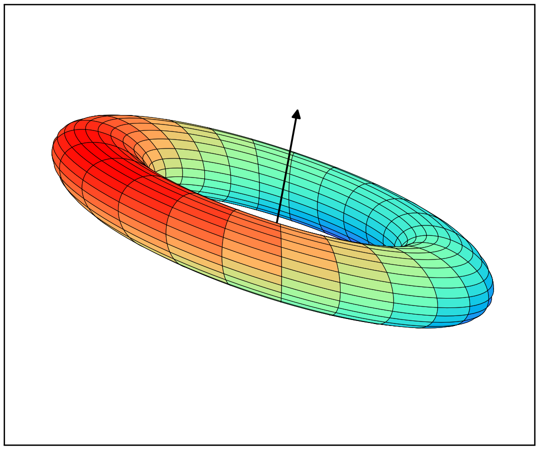

Figure 7: The geometric axis of a torus is shown by the arrow.

Gibbs free energy A type of thermodynamic potential, usually denoted G, given by $G = U + PV - TS$ where U is internal energy, P is pressure, V is volume, T is temperature, and S is entropy. It measures maximum amount of work that may be performed by a system at constant pressure and temperature.

glow discharge A low density and low temperature plasma discharge that glows (for example, fluorescent lights).

Grad-Shafranov equation An equation that determines two-dimension equlibrium between pressure, current density and magnetic field. Usually written as $\Delta^*\psi = -\mu_0 R^2 \frac{\mathrm{d}p}{\mathrm{d}\psi} - F\frac{\mathrm{d}F}{\mathrm{d}\psi}$ where $p(\psi)$ is the pressure in terms of a flux label, $F = RB_\zeta$ and $\Delta^*\psi = R\frac{\partial}{\partial R}\left(\frac{1}{R}\frac{\partial\psi}{\partial R}\right) + \frac{\partial^2\psi}{\partial Z^2}$.

Greenwald limit A density limit on tokamaks that is $n_G = \frac{I_p}{\pi a^2}$ where I_p is the plasma current measured in MA, a is the minor radius in m, and n_G is the density over 10^{20} m^{-3}. Above this density, disruptions commonly occur. The mechanism behind the limit is not fully understood.

g

group velocity For two waves of similar frequency (i.e., $\omega_2 - \omega_1 \ll 1$) superimposed to form one wave, it is defined as $v_g = \frac{\mathrm{d}\omega}{\mathrm{d}k}$ with ω the angular frequency and k the wave number. It is conventionally thought of as the velocity at which information is propagated, although for certain media this interpretation is not true.

guiding center Particles in a uniform magnetic field follow field lines gyrating in a circle around the field line. In more general cases, the particle can be thought to have some path it is gyrating in a circle around, and the center of that circle is the guiding center. In this picture, the particle drifts because the guiding center position is changing.

gyroBohm scaling This is a scaling law for transport similar to **Bohm scaling** except that it includes a dependence on ion **gyroradius**. That is it includes a single factor of **normalized gyroradius** $\rho^* = \rho_i/L$ where ρ_i is the ion gyroradius and L is the characteristic length for transport (usually a, the **minor radius**).

gyrofrequency See **cyclotron frequency**.

gyrokinetics This is **kinetic theory** but with the fast gyromotion averaged out. Thus the **kinetic equation** is modified and one deals with a five dimensional space (three spatial and two velocity). This is like treating the particles as at the center of their **gyroorbits**.

gyroLandau fluid This is a model that introduces Landau damping through an imaginary heat flux ($\mathbf{q}$) where closures are made through $\mathbf{q} = \mathbf{q}_* + i\mathbf{q}_{\mathrm{GL}}$ where $\mathbf{q}_{\mathrm{GL}}$ is the gyroLandau fluid heat flux.

gyroradius See **cyclotron radius**.

gyrotron A device to bunch electrons with cyclotron motion by a strong (straight) magnetic field that produces microwaves. It is a type of free electron maser and can produce high power at millimeter wavelengths. This is a significant advantage over **klystrons** and **magnetrons** because those devices must become smaller (limiting their power handling) as they produce smaller wavelengths, while gyrotrons can be much larger than the wavelengths they are producing.

gyroviscosity This is the **viscosity**-like effect due to gyromotion. There is no viscous heating (dissipation) so that it is a bit of a misnomer to call it a viscosity, but gyroviscosity terms are still a part of the viscous stress tensor in the magnetized case and hence the name. See also **gyroviscous tensor**.

gyroviscous cancellation This is the absence of diamagnetic drift accelerations $\mathrm{d}\mathbf{v}_D/\mathrm{d}t$ where $\mathbf{v}_D$ is the **diamagnetic drift** in drift fluid models of plasmas. That is there is a "cancellation" (in fact, it is not a rigorous cancellation, but a cancellation of convenience, i.e., it simplifies the calculation and does not lead to completely incorrect predictions) of diamagnetic acceleration $m_i n \mathrm{d}\mathbf{V}_{Di}/\mathrm{d}t$ and **gyroviscosity**.

gyroviscous stress tensor See **gyroviscous tensor**.

gyroviscous tensor This is the part of the **stress tensor** due to nondissipative transport of momentum due to spatial variation of the density and the enery of magnetic moments. See also **gyroviscosity**, which this tensor is sometimes called (rather than its nonzero components).

H h

H-mode Stands for high confinement state (or mode). **Energy confinement times** are improved by a factor of two or more over L-mode. Turbulence is suppressed and steep gradients in temperature and desnity occur at the edge of the plasma.

halo During a **vertical displacement event**, the cold, dense plasma formed outside the **last closed flux surface**.

halo current Plasma currents in the **halo** region that connect through the confinement vessel into the plasma.

Hamilton's equations These are equations given by **Hamiltonian mechanics** and are as follows $\frac{\partial \mathcal{H}}{\partial q_j} = -\dot{p}_j$ and $\frac{\partial \mathcal{H}}{\partial p_j} = \dot{q}_j$. The p_j are **generalized momenta** and the q_j are **generalized coordinates**.

Hamilton's principle This is also called the **principle of least action** and states that the trajectory a particle takes, is the one that minimzes its **action**.

Hamiltonian This is a function related to the **Lagrangian**. It is symbolized as H or $\mathcal{H}$, and given by $\mathcal{H}(q_j, \dot{q}_j, t) = \sum_i \dot{q}_i p_i - L(q_j, \dot{q}_j, t)$. It is simply the sum of **kinetic energy** and **potential energy** in systems where the total energy is conserved. The Hamiltonian has nice properties, but its main utility came in **quantum mechanics**, where it is more prominent as an operator associated with time evolution.

Hamiltonian mechanics This is **mechanics** under the **Hamiltonian** formalism. One usually forms the **Hamiltonian** from the **Lagrangian** and applies **Hamilton's equations** to find the **equations of motion**, however **Hamilton's principal** can be used to formulate Hamiltonian mechanics.

Hasegawa-Mima equation This is an equation in plasma physics that models 2D **drift wave turbulence**. It is given by $\frac{\partial}{\partial t}[(1-\nabla^2)\phi] - \nabla\phi \times \hat{\mathbf{z}} \cdot \nabla\nabla^2\phi + \frac{\rho_s}{L_n}\frac{\partial \phi}{\partial y} = 0$, where z is out of plane, y is the direction with a density gradient, ϕ represents the electric potential, ρ_s is the ion sound-gyroradius (i.e., $\rho_s = C_s/|\Omega|$ where C_s is the **ion acoustic speed** and Ω is the **gyrofrequency**), and $L_n^{-1} = \frac{1}{n_0}\frac{\mathrm{d}n_0}{\mathrm{d}x}$ represents the normalized density gradient (usually treated as a constant). Note that in this equation time is normalized to ρ_s/C_s, spatial scales to ρ_s, and the electric potential to T_e/e (with T_e the electron temperature).

heat capacity The heat capacity at constant pressure or volume is usually denoted C_P or C_V, respectively. Sometimes when context makes it obvious which it is, it is just C. It is measured in J/K, and is a measure of how much the temperature of a substance changes due to the input or loss of heat energy. Usually used in $Q = C\Delta T$ where Q is the heat and T is the temperature in Kelvin.

heat capacity ratio See **adiabatic constant**.

heliac A toroidal confinement device where the **stellarator**-like field is imposed on a **tokamak**-like poloidal field. That is, the plasma instead of being a simple ring also has a helix shape. It is considered a type of **stellarator**.

helicity (1) Plasma Physics. A measure of how linked the magnetic fields are (or how much they wrap around each other) given by $\int \mathbf{A}\cdot\mathbf{B}\,\mathrm{d}^3r$, where $\mathbf{A}$ is the **magnetic vector potential**, and $\mathbf{B}$ is the magnetic field. While in general this is not **gauge-invariant**, there are defintions and conventions making the concept **gauge invariant**. Note helicity is conserved when in a perfectly conducting fluid. (2) Particle Physics. This is the projection of spin onto momentum, $\mathbf{S}\cdot\mathbf{p}$. (3) Fluid Mechanics. This gives how helical the motion of particles in the fluid are. $\int \mathbf{u}\cdot(\boldsymbol{\nabla}\times\mathbf{u})\,\mathrm{d}^3x$ with $\mathbf{u}$ being the fluid velocity.

helicon In plasma physics, this is a low-frequency electromagnetic wave requiring a background magnetic field in an electron plasma. These waves can propagate through metals and have a dispersion relation of the form $\omega = \frac{|\Omega_e|}{\omega_{pe}^2}c^2k^2$ with Ω_e the electron **cyclotron frequency**, ω_{pe} the **plasma frequency**, c the speed of light, and k the wavenumber. Note these are like **whistler waves**, except that whistler waves occur in electron-ion plasmas.

heliosphere A region of space surrounding the sun that is supported by plasma blown out from the sun. Experimentally, it is found by finding where the solar wind abruptly slows down.

Helmholtz free energy A type of thermodynamic potential, usually denoted A or F, given by $F = U - TS$ where U is internal energy, T is temperature, and S is entropy. It measures the maximum amount of work a system can perform when the volume is held constant.

herpolhode Imagine an ellipsoid on a fixed plane. As the ellipsoid rolls on the plane, the point of contact between the fixed plane and the ellipsoid will draw a curve on the fixed plane. This is the herpolhode. More generally any object on a fixed plane, the "point of contact" will draw the herpolhode on the fixed plane. See Figure 8.

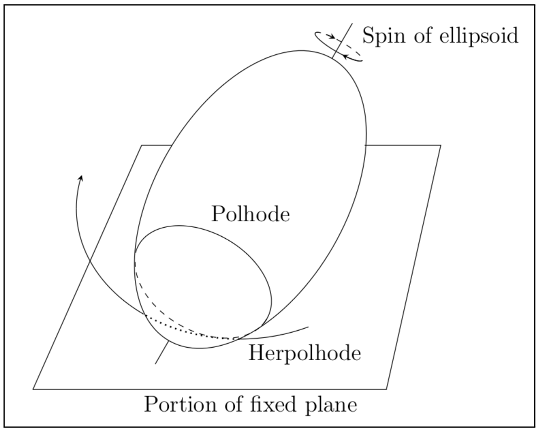

Figure 8: Herpolhode and polhode.

HFS See **high field side**.

high field side Often abbreviated **HFS**. In a **tokamak**, this is the **inboard** side of the torus.

highly ionized plasma A plasma where collisions between charged particles plays a larger role in the dynamics of the system than collisions between neutrals. In general, the plasma has most of its particles ionized, but it is possible to have few ($\sim 1\%$) of the particles ionized and still be considered a highly ionized plasma.

Hilbert space A **space** that is both a **complete metric space** and an **inner product space** (real or complex).

Hilbert transform The Hilbert transform of $f(t)$ is given by $H(f) = \frac{1}{\pi} ⨍ \frac{f(\tau)}{t-\tau} \mathrm{d}\tau$ where $⨍$ indicates the **Cauchy principal value**.

hohlraum German meaning hollow space. A hollow chamber around a fusion capsule that converts energy into X-rays. Used in **inertial confinement fusion**.

homogeneous function A homogeneous function is a function f that satisfies $f(\alpha x_1, \alpha x_2, \ldots, \alpha x_n) = \alpha^k f(x_1, x_2, \ldots, x_n)$ for some k. It is then said to be homogeneous of degree k.

Hooke's law A simple relation between the force applied by a material due to a displacement. It is usally written $F = -kx$, where k is a "spring constant" telling how strong the restoring force is for a displacement.

hot plasma A plasma with high temperature ions and electrons.

hybrid resonance A resonance in a plasma involving both **plasma frequency** and the **cyclotron frequency**.

hydrodynamic instability An instability arising from the fluid mechanic aspects. The **Rayleigh-Taylor instability** is a well-known example.

hysteresis This is when a system depends not only on its current environment, but on its past environment as well. This is often stated as a path-dependent system.

I i

i.e. Latin. Short for *id est.* This translates as "that is".

ia. Latin. Short for ***inter alia***.

ibid. Latin. Short for *ibidem.* It translates as "in the same place" and is usually used in footnotes for references.

ICE See **ion cyclotron emission**.

ICRF Ion Cyclotron Range of Frequency. A mechanism to heat up plasmas by using the ion **cyclotron frequency**.

ICRH See **Ion Cyclotron Resonance Heating**.

id. Latin. Short for *idem.* It translates as "the same" and is usually used in footnotes to indicate it is using the same reference as the previous one. Technically in Latin this is only for men, and *ead.* should be used for women, but only id is usually used in practice.

ideal MHD A version of MHD in which the plasma is considered a perfect conductor. For example, the **Ohm's Law** is $\mathbf{E} = -\mathbf{v} \times \mathbf{B}$.

ideal wall In plasma physics, this refers to a perfectly conducting wall (not a superconducting wall). That is, the conductivity goes to ∞, $\sigma \to \infty$, or resistivity goes to zero, $\rho \to 0$, for the material in the wall. A perfect conductor does not exhibit the expulsion of flux called the **Meissner effect**.

ignition This is the break-even point, where the energy coming from fusion is enough to keep the fusion process going, and so there is no need for external energy. Another way of saying this is the heat necessary to keep fusion going is provided by the fusion reactions themselves.

inboard On a toroidal device, this is the inner surface near the center or hole. For **tokamaks**, it is also called the **high field side** or **HFS** because the magnetic field is larger near the hole of the torus.

incompressible closure This is a **closure** of the fluid hierarchy where $\nabla \cdot \mathbf{V} = 0$, where the **divergence** of the **flow velocity** is zero everywhere. It is also where dynamics are slow compared to sound wave propagation.

incompressible vector field See **solenoidal field**.

index of refraction This is a dimensionless number that helps describe how light propagates in a medium. It is usually denoted by n, with $n = \frac{ck}{\omega} = \frac{c}{\nu\lambda} = c/v$. with k the **wavenumber**, ω the angular frequency, ν the frequency, λ the wavelength, v the velocity, and c the speed of light in vacuum.

indirect drive In **inertial confinement**, when the laser does not directly hit the pellet, but causes some other process to happen to implode the fuel pellet.

inductively coupled discharge This creates a plasma by applying a radiofrequency oscillating voltage across an inductive coil, which accelerates the electrons in the plasma.

inertial confinement A type of fusion scheme where the fuel is imploded quickly enough that inertia prevents the particles from dispersing, and so fusion occurs quickly enough (and with enough reactions) that significant energy is released.

inertial frame A **coordinate frame** where **Newton's second law** holds.

inertial range cascade This is a cascade of energy (or some other energy-like quantity) from either large to small scales, or small to large scales. An inverse cascade involves going from small to large scales, whereas a forward cascade involves going from large to small scales. It is inertial if the amount of energy going in at any scale is the same as the amount of energy going out at that scale.

inner product A function that takes two elements from a **space**, x and y (also let z be in the space), and denoted $\langle x, y\rangle$ has the properties [1] $\langle x, y\rangle^* = \langle y, x\rangle$ where * denotes conjugation (if x and y are real or complex numbers, then **complex conjugation**), [2] with λ a scalar in the space $\langle \lambda x, y\rangle = \lambda \langle x, y\rangle$ and $\langle x + z, y\rangle = \langle x, y\rangle + \langle z, y\rangle$ and that [3] $\langle x, x\rangle \geq 0$ with $\langle x, x\rangle = 0$ only for $x = 0$. Note that this yields $\langle x, \lambda y\rangle = \lambda^* \langle x, y\rangle$ and $\langle x, y + z\rangle = \langle x, z\rangle + \langle x, z\rangle$.

inner product space A space with an **inner product** defined on it consistently.

instability A phenomenon in a system where for a small perturbation, the small pertubation leads to a large change in the state of the system. Generally it involves growing exponential change over time in some physical quantity.

inter alia Latin. Meaning "among other things".

interchange instability This is an instability in plasmas due to **bad (field) curvature**. In a cylindrical configuration, the curvature wants magnetic field to come inwards and the pressure gradient wants to go outward so there is a lower energy state possible which

i

releases the plasma. Also see **Rayleigh-Taylor instability**. These instabilities are pressure driven.

intergalactic plasma The low density plasma in between galaxies.

internal inductance For plasmas, this is the part of the inductance due to integrating over the volume of the plasma. The total inductance is given by the sum of internal and external inductance. Denoted $L_i = \frac{2}{I^2}\int_{V_p} \mathrm{d}^3x\, \frac{B^2}{2\mu_0}$ where V_p is the volume of the plasma. One often deals with a normalized internal inductance denoted $\ell_i = \frac{2L_i}{\mu_0 R_0}$ where R_0 is the major radius.

i

internal transport barrier Usually shortened to **ITB**. A radial zone in a toroidal plasma (in a **tokamak**, **stellarator**, or **RFP**, for example) with steep gradients (in number density, temperature, and/or pressure), but not out at the far edge (usually about half-way to the edge of the plasma). Typically, these steep gradients lead to improved energy confinement, and so better transport characteristics for a fusion reactor.

International System of Units Usually shortened to **SI** from *Le Système international d'unités*. A system of units with base units of meter (m), kilogram (kg), second (s), Ampère (A), and candela (cd).

International Thermonuclear Experimental Reactor See **ITER**.

interstellar medium See **interstellar plasma**.

interstellar plasma The low density plasma in between stars. Often called the **interstellar medium**.

inverse aspect ratio This is the **minor radius** over the **major radius** usually denoted $\epsilon = \frac{r}{R}$. See also **aspect ratio**.

ion A positively or negatively charged particle. In plasma physics, ions are almost always positively charged, though not always.

ion acoustic wave A compressional **plasma wave** in the ion density of a plasma.

ion Bernstein wave See **Bernstein wave**.

ion cyclotron emission Also known as **ICE**. When ions gyrate in a magnetic field, they are accelerating, and so are radiating, which gives this emission.

ion cyclotron resonance heating Also known as **ICRH**. This is heating of the plasma by applying a radiofrequency near the ion **cyclotron resonance**, which excites the ions, which then **thermalize** with the rest of the plasma.

ion diode Device that produces and accelerates ion beams for **inertial confinement**.

ion implantation Process for material hardening by putting ions in the surface layers of the material.

ion temperature gradient Also known as **ITG**. This usually refers to an instability in plasmas due to a gradient in temperature of the ions.

ionize A process that causes a particle to lose or gain an electron or electrons from its neutral state and so become an ion.

ionized gas A synonym for a **plasma**.

ionosphere A region of space in the atmosphere of a planet where the atmospheric gases are ionized by solar radiation.

isentropic expansion factor See **adiabatic index**.

island healing A process that causes **magnetic islands** to disappear.

isolated system A system that cannot exchange energy nor matter with anything outside of the system's boundaries. Compare **closed system** which can exchange energy.

isothermal closure A **closure** in the fluid hierarchy where dynamics are slow compared to thermal dynamics or **thermal conduction** is large. This effectively means that temperature everywhere in the region of interest is constant.

ITB See **internal transport barrier**.

ITER This used to be short for **International Thermonuclear Experimental Reactor** (as well as Latin for "the way", "the road", or most properly "the journey"), but it now has no meaning for the letters. A large tokamak research reactor that will try to make commercial thermonuclear power conceivable for the future via studying **burning plasmas**.

ITG See **ion temperature gradient**.

J j

j

Jacobian This is the matrix of partial derivatives between two coordinate systems (often the determinant of the matrix is called the Jacobian, as well). Often denoted J or $\mathcal{J}$. The latter, $\mathcal{J}$ is often the determinant of the Jacobian. The volume element d^3x is defined for a specific coordinate system $(\xi^1(x^1,x^2,x^3),\xi^2(x^1,x^2,x^3),\xi^3(x^1,x^2,x^3))$ as $\mathrm{d}^3x = \mathcal{J}\,\mathrm{d}\xi^1\,\mathrm{d}\xi^2\,\mathrm{d}\xi^3$ with $\mathcal{J}$ the determinant. Conventionally defined (for 3 dimensions) as

$$\mathcal{J} = \begin{bmatrix} \frac{\partial\xi^1}{\partial x^1} & \frac{\partial\xi^1}{\partial x^2} & \frac{\partial\xi^1}{\partial x^3} \\ \frac{\partial\xi^2}{\partial x^1} & \frac{\partial\xi^2}{\partial x^2} & \frac{\partial\xi^2}{\partial x^3} \\ \frac{\partial\xi^3}{\partial x^1} & \frac{\partial\xi^3}{\partial x^2} & \frac{\partial\xi^3}{\partial x^3} \end{bmatrix}$$

although the transpose of this is sometimes called the Jacobian. Other notation is $\frac{\partial(\xi^1,\xi^2,\xi^3)}{\partial(x^1,x^2,x^3)}$. In addition the inverse Jacobian $\frac{\partial(x^1,x^2,x^3)}{\partial\xi^1,\xi^2,\xi^3)}$ is sometimes considered the "Jacobian" depending on the convention of the particular text.

JET See **Joint European Torus**.

Joint European Torus Also **JET**. A tokamak in Culham, United Kingdom.

Joule heating See **ohmic heating**.

JT-60 A tokamak that was in Japan. From Japan Torus-60.

JT-60U An upgrade to the tokamak **JT-60** in Japan. It is essentially an entirely new tokamak, rather than an "upgrade" as conventionally conceived.

K k

KBM See **kinetic ballooning mode**.

kelvin A **temperature** unit where 0 K is **absolute zero**.

kinetic ballooning mode This is an instability/mode due to a **ballooning mode**, but not purely driven by **MHD**. Kinetic effects of **kinetic theory** such as turbulent transport can cause these.

k

kinetic energy This is the **energy** that is associated with a particle moving at a **velocity**. It is given classically by $\frac{1}{2}mv^2$ and (special) relativistically by $(\gamma - 1)mc^2$ for γ the **Lorentz factor**.

kinetic equation In plasma physics, this is the equation that governs the evolution of the **distribution function** for the plasma particles. It is given by the **Vlasov equation** with a **collision operator**. If the distribution function is given by f, $\mathbf{v}$ is the velocity space coordinate, and $C(f)$ is the collision operator then the kinetic equation for plasmas is written $\frac{\partial f}{\partial t} + \mathbf{v} \cdot \frac{\partial f}{\partial \mathbf{x}} + \frac{q}{m}(\mathbf{E} + \mathbf{v} \times \mathbf{B}) \cdot \frac{\partial f}{\partial \mathbf{v}} = C(f)$. The most general form is given by $\frac{\partial f}{\partial t} + \mathbf{v} \cdot \frac{\partial f}{\partial \mathbf{x}} + \mathbf{a} \cdot \frac{\partial f}{\partial \mathbf{v}} = C(f)$ where $\mathbf{a}$ is the acceleration.

kinetic theory The theory of how particles interact at a particle-particle level in a many particle system giving rise to collective effects, similar to **statistical mechanics**. It is very broad in apnplicability because it does not require thermodynamic equilibrium.

kink instability See **kink mode**.

kink mode A **MHD instability** driven by current. Called a kink because it drives the plasma column to "kink" on itself. See Figures 9, 10, 11, 12.

kink safety factor A parameter measuring how safe from a **kink mode** a plasma is. Usually denoted $q_* = \dfrac{2\pi a^2 \kappa B}{\mu_0 R I}$ (SI) or $q_* = \dfrac{2\pi a^2 c \kappa B}{4\pi R I} = \dfrac{a^2 c \kappa B}{2 R I}$ (Gaussian) with a the **minor radius**, R the **major radius**, B is applied toroidal magnetic field, I the total toroidal current, and $\kappa = \frac{A}{\pi a^2}$ where A is the cross section of the reactor (coming from the **magnetic curvature** vector $\boldsymbol{\kappa}$).

klystron A type of microwave amplifier. Its advantages over a **magnetron** are precisely controlled amplitude, frequency, and phase of the output.

Knudsen number This is a dimensionless parameter that characterizes the collisionality of a system. It is typically given as $\mathrm{Kn} \equiv \lambda_{\mathrm{mfp}}/L$ where $\lambda_t mfp$ is the **mean free path** and L is a characteristic length. The larger the Knudsen number the less collisional (more collisionless) the system is.

Kramers-Kronig relations Given a complex function $\chi(\omega) = \chi_r(\omega) + i\chi_i(\omega)$ which is analytic in the upper half of the complex plane and vanishes like $1/|\omega|$ or faster as $|\omega| \to \infty$ with χ_r, χ_i both real-valued, one finds

$$\chi_r(\omega) = \frac{1}{\pi} ⨍_{-\infty}^{\infty} \frac{\chi_i(\omega')}{\omega' - \omega}\, \mathrm{d}\omega'$$
$$\chi_i(\omega) = -\frac{1}{\pi} ⨍_{-\infty}^{\infty} \frac{\chi_r(\omega')}{\omega' - \omega}\, \mathrm{d}\omega'$$

where $⨍$ indicates the **Cauchy principal value**. Physically, the Kramers-Kronig relations apply to causal systems. That is, if we want the response of a system to an externsal source to follow the external response in time we require certain functions to satisfy the Kramers-Kronig relations (such as in plasma physics, the **electrical susceptibility**).

Kronecker delta This is a symbol (usually not a tensor) which is 1 when all of its indices are the same, and zero otherwise. It is denoted $\delta_{i_1,i_2,\ldots,i_N}$. Only when $i_1 = i_2 = \cdots = i_N$ is $\delta_{i_1,i_2,\ldots,i_N} = 1$. If one writes this out, however, using the **Einstein summation notation** with i_n having N possible values, then $\delta_{i_1,i_1,\ldots,i_1} = N$. Generally, one is interested in δ_{ij} where $i, j = 1, 2, 3$ so that $\delta_{11} = \delta_{22} = \delta_{33} = 1$ and is zero otherwise. Using summation notation, $\delta_{ii} = 3$.

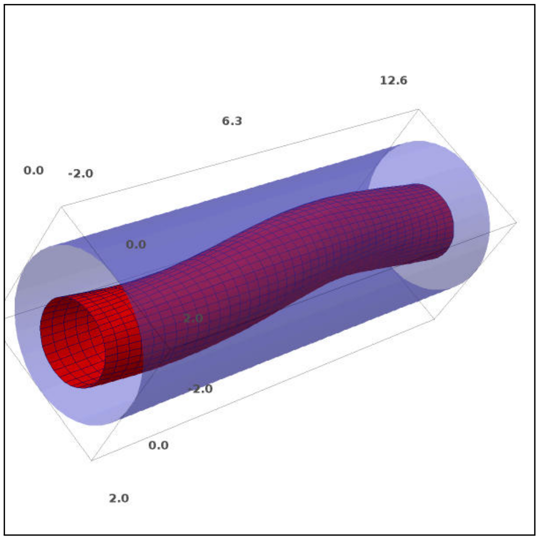

Figure 9: A $m = 1$, $n = 1$ kink instability. The transparent tube represents an axisymmetric surface.

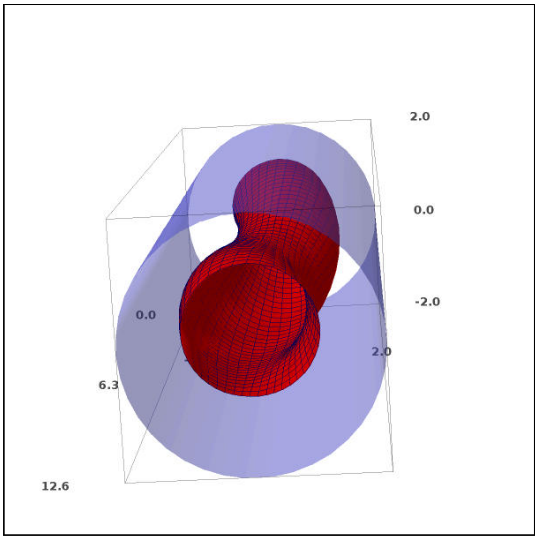

Figure 10: A $m = 1$, $n = 1$ kink instability. The transparent tube represents an axisymmetric surface.

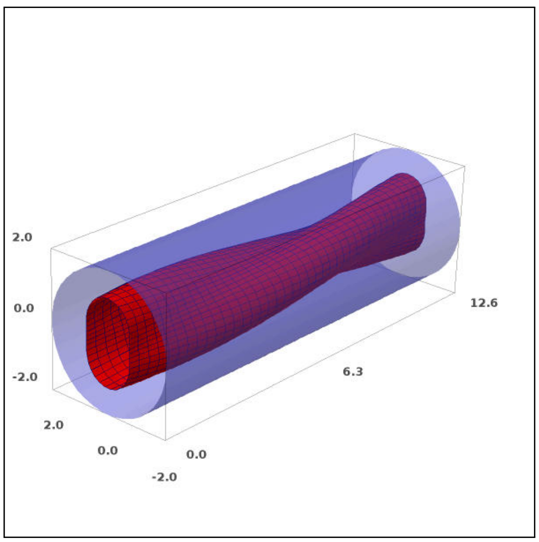

Figure 11: A $m = 2$, $n = 1$ kink instability. The transparent tube represents an axisymmetric surface.

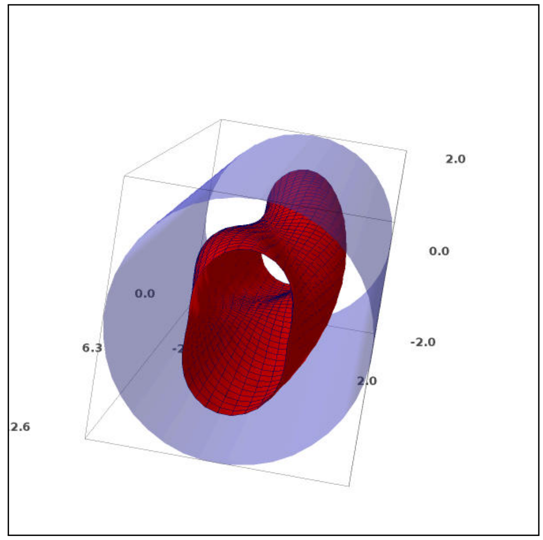

Figure 12: A $m = 2$, $n = 1$ kink instability. The transparent tube represents an axisymmetric surface.

L l

L-mode The low confinement state where energy confinement times are not as good as in **H-mode**.

Lagrange's prime notation The notation of using a prime to denote **differentiation**. For example, $f(x)' = f' = \frac{\mathrm{d}f}{\mathrm{d}x}$.

Lagrangian A function that is (classically) the **kinetic energy** minus the **potential energy**. Under **Lagrangian mechanics**, this function can be used to determine the **equations of motion**. Usually denoted as L or $\mathcal{L}$ so that $L = T - U$ (T being kinetic energy, and U being potential energy) in most situations, although $\mathcal{L}$ is sometimes used for the Lagrangian density, i.e., the kinetic energy density minus potential energy density. In relativistic contexts the Lagrangian is no longer the kinetic energy minus the potential energy, but given by $L(\mathbf{x}, \mathbf{v}, t) = -\frac{m_0 c^2}{\gamma(\mathbf{v})} - V(\mathbf{x}, \mathbf{v}, t)$ with $\mathbf{x}$ the position, $\mathbf{v}$ the velocity of the particle, t the time, and γ the **Lorentz factor**. *Not* to be confused with **Lagrangian coordinates** of solid and fluid dynamics.

Lagrangian coordinates These are coordinates in fluid or solid mechanics. Given a parcel of material initially at location $\mathbf{x}_0$, the Lagrangian coordinate gives the location of the parcel at a later time t as $\mathbf{X}(\mathbf{x}_0, t)$. This means that flows are looked at as the movement of the parcels rather than velocities at a certain position. This method of locating material movement is to be compared to **Eulerian coordinates**. The connection between Eulerian coordinates and Lagrangian coordinates is $\mathbf{v}(\mathbf{X}(\mathbf{x}_0, t), t) = \frac{\partial \mathbf{X}(\mathbf{x}_0, t)}{\partial t}$ for **flow velocity** v. *Not* to be confused with **generalized coordinates** of **Hamiltonian mechanics** or **Lagrangian mechanics**.

Lagrangian mechanics This is **mechanics** under the **Lagrangian** formalism. One usually forms the Lagrangian and applies the **Euler-Lagrange equations** to find the **equations of motion**.

laminar flow A flow pattern where the **fluid** may be divided into parallel layers which flow past each other with different velocities. This is to be contrasted with turbulent flow where the fluid layers do not simply flow past each other but cause swirls and vortices.

Landau damping This refers to the damping of a wave propgating in a **hot plasma** without collisions. The damping is explained as due to phase mixing (i.e., different particle velocities interacting with the background fields). A simplified picture (the "surfer model") uses particle and wave resonant interactions, but this is a cartoon version of the actual physical picture, and without proper caveats can mislead as much as it guides intuition. The previous comments are for linear Landau damping. Finding a "definitive" description of Landau damping is difficult, and the idea that there actually are no collisions becomes questionable. More advanced treatments consider weak Coulomb collisions to justify the idea physically.

Langmuir frequency See **plasma frequency**.

Langmuir oscillation See **plasma oscillation**.

Langmuir probe A small conducting probe that is put into the edge of the plasma to determine density, temperature, and electric potential of the plasma. Often made of tungsten or some material that can withstand the high temperatures in a plasma.

Langmuir wave See **plasma oscillation**.

Larmor frequency See **cyclotron frequency**.

Larmor radius See **cyclotron radius**.

laser wakefield acceleration See **wakefield acceleration**. The mechanism in this case is a laser rather than an electron beam.

last closed flux surface Often denoted **LCFS**. As it sounds, it is the last **flux surface** that is closed as one goes out from the **magnetic axis** in a torus.

Lawson criterion Criterion that determines whether the plasma is capable of self-sustained fusion. $n_e T \tau_e \geq 10^{21}$ keV s/m^3 with n_e electron number desnity, T the temperature, τ_e the **energy confinement time**.

LCFS See **last closed flux surface**.

left circularly polarized wave A type of wave allowed in plasmas that is left-handed in the sense that having your thumb on your left hand point in the direction of propagation you would find the polarization curls as your fingers do.

Leibniz notation The standard fraction-like notation for a derivative. For example the derivative with respect to x of the function f is denoted $\frac{\mathrm{d}f}{\mathrm{d}x}$.

LFS See **low field side**.

lightning An electrical discharge between clouds or the Earth and a cloud.

limiter A structure in a confinement device that is put near the edge of the confinement device that prevents the plasma from hitting the wall.

liquid A substance and state of matter that adapts its shape to its container, but does not spread out to fill the shape of the container as a **gas** does.

local thermal equilibrium Also **LTE**. A system is in local thermal equilibrium when its particle follow a Maxwellian distribution and the system radiates as a blackbody at the Planckian temperature.

longitudinal invariant Generally called the second **adiabatic invariant** and is denoted $J = \int_a^b p_{\parallel}\,\mathrm{d}s$ where the integral is done on a fixed magnetic field line and a and b are two turning points, i.e., two points where the particle reverses its parallel motion direction. Often $v_{\parallel}$ is used instead of $p_{\parallel}$ in the integral. Usually called the second adiabatic invariant.

longitudinal wave A wave that has the variation of the disturbance in the same direction as propagation or partly in the propagation direction.

loop voltage This is the voltage measured from a loop toroidally (the long way) around the torus of the plasma. This gives information about the inductive coupling between the plasma and transformer (and if using non-inductive heating, it is muddied by coupling from non-inductive heating).

Lorentz collision model A model for a plasma in which the background charged particles are all infinitely massive (they do not move in collisions) and randomly and isotropically distributed in space. Then the test particle (which is light compared to the background particles) deflects off of the background particles.

Lorentz factor Typically denoted by γ, it is the factor $\left(1 - \frac{v^2}{c^2}\right)^{-1/2}$ where v is a particle's velocity and c is the speed of light.

Lorentz force The force due to electromagnetic contributions. Given as $\mathbf{F} = q\left(\mathbf{E} + \mathbf{v} \times \mathbf{B}\right)$ (SI) or $\mathbf{F} = q\left(\mathbf{E} + \frac{\mathbf{v}\times\mathbf{B}}{c}\right)$ (Gaussian).

Lorentz gas See **electron gas**. A specific model with fixed, isotropic scattering sites. See **Lorentz collision model**.

low field side Often abbreviated **LFS**. In a **tokamak**, this is the **outboard** side of the device. It is called the low field side, because the magnetic field is weakest on the outside (furthest from hole) of a tokamak.

lower hybrid frequency The frequency at which a lower hybrid wave propagates. The frequency is $\omega = \sqrt{(\Omega_i \Omega_e)^{-1} + \omega_{pi}^{-2}}$ where ω_{pi} is the ion plasma frequency. Useful for **lower hybrid heating** as there is a resonance at this frequency.

lower hybrid heating Plasma heating due to the lower hybrid frequency.

LTE See **local thermal equilibrium**.

Lundquist number This is a dimensionless number of plasma physics. It is usually denoted $S = \frac{\mu_0 v_A L}{\eta}$, where μ_0 is the **permeability of free space**, v_A is the **Alfvén speed**, L is a characteristic length, and η is the electrical resistivity. The value can also be interpreted as $S = \frac{\mathbf{J}\times\mathbf{B}}{\text{resisitive diffusion}}$ forces, or $S = \frac{\tau_r}{\tau_A} = \frac{\frac{\mu_0 L^2}{\eta}}{\frac{L}{v_A}}$ where τ_r is a resistive time scale and τ_A is the **Alvén time**. Note that the **magnetic Reynolds number** is the same as the Lundquist number when $v = v_A$ in the **magnetic Reynolds number**.

l

M m

magnetic axis In a toroidal geometry, this is the axis going through the center of the inside of the torus in the toroidal direction. See figure 14.

magnetic bottle A term describing a region of **magnetic confinement**.

magnetic confinement The use of magnetic fields to confine a plasma, generally in order to create fusion conditions.

magnetic connection length See **connection length**.

m

magnetic constant See **permeability of free space**.

magnetic curvature A vector that describes how the magnetic field curves. It is given by $\boldsymbol{\kappa} = \hat{\mathbf{b}} \cdot \nabla \hat{\mathbf{b}}$ where $\hat{\mathbf{b}}$ is the unit vector in the magnetic field direction.

magnetic diffusivity This measures the tendency of the magnetic field to diffuse throughout a medium, $\eta_D = \frac{\eta}{\mu_0} = \frac{1}{\sigma \mu_0}$ where η_D is the magnetic diffusivity, η is the electrical resistivity, $\sigma = 1/\eta$ is the electrical conductivity, and μ_0 is the permeability of free space. Unfortunately, magnetic diffusivity is often denoted η, so that it is easily confused with electrical resistivity within plasma literature.

magnetic field curvature See **magnetic curvature**.

magnetic flux For a given surface, the amount of magnetic field directed normally through the surface with units of Tesla-meter^2 or Webers (Wb). It is generally called the third **adiabatic invariant**, although in most applications is not actually invariant and so is not used often for this application.

magnetic flux surface See **flux surface**.

magnetic island When plotting magnetic field contours, when instead of having many nested surfaces, one of the contours forms an "island" closing on itself. This region is known as the magnetic island.

magnetic mirror A cylindrical device that is straight and confines plasmas through magnetic fields at the ends which act like a mirror to bounce back particles that would go out the ends. Problems with this approach (too many particles being lost through the ends by not being bounced back) are still under investigation as **gas dynamic traps** or **GDTs**.

magnetic mirror ratio See **mirror ratio**.

magnetic moment Usually refers to a magnet's magnetic dipole moment which tells how the magnet will react to torques and what the minimum energy state is. Often denoted **m**. For plasma physics this usually refers to the magnitude of the magnetic moment of a gyrating particle and is denoted $\mu = \dfrac{mv_\perp^2}{2B}$ (SI) or $\mu = \dfrac{mcv_\perp^2}{2B}$ which is also called the first **adiabatic invariant**.

magnetic Prandtl number This is a dimensionless number of plasma physics analogus to the **Prandtl number** usually denoted $\mathrm{Pr_m} = \frac{\mathrm{Re_m}}{\mathrm{Re}} = \frac{\nu}{\eta_D} = \frac{\mu_0 \nu}{\eta}$ where Re is the **Reynolds number**, $\mathrm{Re_m}$ is the **magnetic Reynolds number**, ν is **kinematic viscosity**, and $\eta_D = \eta/\mu_0$ is **magnetic diffusivity** (η is electrical resistivity and μ_0 is the **permeability of free space**). It can be interpreted as $\mathrm{Pr_m} = \frac{\text{viscous}}{\text{magnetic}}$ diffusion.

magnetic pressure This is the energy density of the magnetic field. This has the same units as pressure, and can be thought of as the magnetic lines applying pressure to the plasma. It is equal to $\frac{B^2}{2\mu_0}$ in SI or $\frac{B^2}{8\pi}$ in Gaussian units.

magnetic pumping Plasma heating through plasma compression and expansion via osciallating external magnetic field.

magnetic reconnection When a plasma has finite resistivity, the **frozen flux theorem** no longer holds, and the magnetic field can change its **topology**, so that magnetic field lines can connect with each other. The process of magnetic field line topology change is called magnetic reconnection.

magnetic Reynolds number This is a dimensionless number of plasma physics analogous to the **Reynolds number** in fluid mechanics. It is usually denoted $\mathrm{R_m} = \frac{vL}{\eta_D} = \frac{\mu_0 v L}{\eta}$ where $\eta_D = \eta/\mu_0$ is the magnetic diffusivity (μ_0 is the permability of free space and η is the electrical resisitivity), v is a characteristic velocity and L is a characteristic length. It may be interpreted as $\mathrm{R_m} = \frac{\text{flow velocity}}{\text{magnetic diffusion}}$ force. Note when $v = v_A$ that the magnetic Reynolds number is the same as the **Lundquist number**.

magnetic shear This is the amount of differential twisting. The local shear for a field $\mathbf{B} = B\hat{\mathbf{b}}$ is given by $\boldsymbol{\sigma} \equiv \frac{(\hat{\mathbf{b}} \times \nabla\psi) \cdot \nabla \times (\hat{\mathbf{b}} \times \nabla\psi)}{|\hat{\mathbf{b}} \times \nabla\psi|^2} = \frac{(\hat{\mathbf{B}} \times \nabla\psi) \cdot \nabla \times (\mathbf{B} \times \nabla\psi)}{B^2 |\nabla\psi|^2}$ with ψ the radial variable normal to **flux surfaces**. In plasma physics, the **magnetic shear parameter** is usually used instead and denoted by $s = -R_0 \sigma q$ where q is the **safety factor** and R_0 is the **major radius**. See Figure 13 for an example of a field with shear.

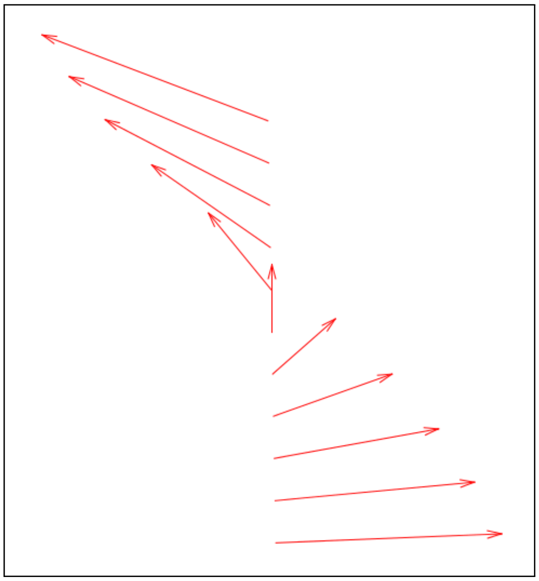

Figure 13: A vector field with shear.

magnetic shear parameter This is the normalized derivative of the **safety factor** and given by $s = \frac{r}{q}\frac{\mathrm{d}q}{\mathrm{d}r} = \frac{\mathrm{d}\ln q}{\mathrm{d}\ln r}$. This is what is usually meant by **magnetic shear**. We use $s > 0$ means positive or "normal" magnetic shear and $s < 0$ means reversed shear. It measures the variation of the **safety factor** from one **flux surface** to the next. The previous comments are from a **tokamak** point of view. For a stellarator, a typical discharge uses a "reversed" shear in the tokamak sense and so stellarators sometimes define magnetic shear $s_s = \frac{r}{\iota\!\!-}\frac{\mathrm{d}\iota\!\!-}{\mathrm{d}r}$ for $\iota\!\!-$ the **rotational transform** with $s_s \propto -s$ with s the shear defined for a tokamak.

magnetic susceptibility This is a dimensionless proportionality constant that indicates the degree of **magnetization** of a material due to an applied magnetic field. Usually denoted χ_m (or just χ if there is no chance of confusion with the **electric susceptibility**), it is defined by $\mathbf{M} = \chi_m \mu_0 \mathbf{M}$ with $\mathbf{M}$ the magnetization, μ_0 the **permeability of free space**, and $\mathbf{M}$ the magnetic field.

magnetic vector potential This is a **vector potential**, $\mathbf{A}$, that can be used to find the magnetic field, $\mathbf{B}$, such that $\boldsymbol{\nabla} \times \mathbf{A} = \mathbf{B}$.

magnetic viscosity A **viscosity** similar to fluid viscosity in that it prevents particles from flowing perpendicular to magnetic field lines, but due to magnetic field lines. Usually denoted η.

magnetic well A configuration where the plasma is confined in a region with the smallest magnetic field amplitude. Usually favorable, as magnetic pressure pushes the plasma back towards this region.

magnetization This is the average of the **magnetic moment** per unit volume. If N particles in a volume V all have magnetic moment $\boldsymbol{\mu}$, then the magnetization $M = N\boldsymbol{\mu}/V$.

magnetized plasma This is a plasma where magnetic field effects are important. Generally if $\delta \equiv \frac{\rho}{L} \ll 1$ then the plasma is magnetized where ρ is the **gyroradius**, L is the characteristic length of the plasma, and δ is the magnetization parameter. Sometimes, the criterion to be magnetized (in experiment usually) $\frac{\nu}{\Omega} \ll 1$ is used instead.

magnetoacoustic wave A longitudinal wave propagating perpendicular to the **B**. Also called **magnetosonic wave**, **compressional Alfvén wave**, or **fast Alfvén wave**.

magnetohydrodyamics MHD. A theory for understanding electrically conducting fluids.

magnetohydrodynamic generator A device that changes energy from a jet of plasma to electrical energy.

m

magnetosonic wave See **magnetoacoustic wave**.

magnetoviscosity See **gyroviscosity**.

magnetron A vacuum tube that generates microwaves.

major radius Usually denoted R, it is the distance from the **geometric axis** to the **magnetic axis** at the center plane of the torus. See Figure 15.

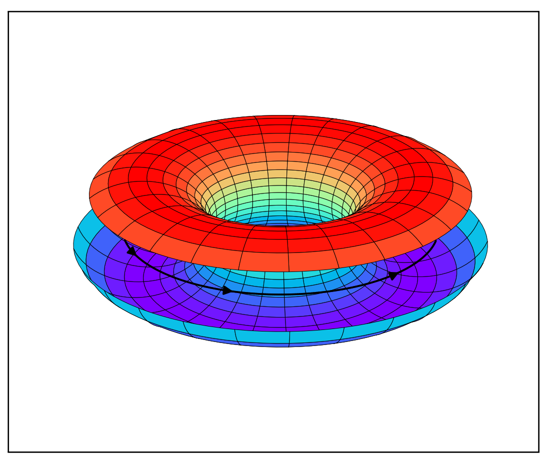

Figure 14: Cutting a section of the torus away so that a possible magnetic axis of the torus can be seen.

Malmberg-Penning Trap A cylindrical trap that confines a plasma with a uniform axial magnetic field, and electrostatic fields at the ends of the cylinder.

massive gas injection In order to prevent **disruptions** from doing major damage to the wall of the experiments, often a bunch of high Z impurities (neon, for example) is injected into the plasma discharge. These impurities radiate the power away in all directions instead of concentrating it on some part of the wall of the device, leading to less overall damage.

MD Short for major **disruption**.

mean free path The typical distance a particle travels (after having just made a collision) before making a collision. Related to the **collision frequency** and **collision time**.

mechanics The study of objects under forces.

Meissner effect This is the phenomenon where a superconductor expels magnetic flux to a thin surface region. Effectively, it pushes magnetic field lines out of the superconductor.

metric Mathematically, a function that takes two arbitrary elements, say x, y, in a **space** and may be denoted here as $\langle x, y\rangle$, which outputs a nonnegative real number (i.e., $\langle x, y\rangle \geq 0$ for all x and y), is zero only when x and y are the same ($\langle x, y\rangle = 0 \Leftrightarrow x = y$), is the same when x and y are interchanged ($\langle x, y\rangle = \langle y, x\rangle$), and obeys the triangle inequality, (letting z also be an arbitary element in the space, $\langle x, z\rangle \leq \langle x, y\rangle + \langle y, z\rangle$).

MGI See **massive gas injection**.

MHD See **magnetohydrodynamics**.

MHD instability A plasma **instability** within the theory of **MHD**.

MHD ordering An ordering of velocities such that $V_E/v_{\text{th}} \sim 1$ where V_E is the $\mathbf{E} \times \mathbf{B}$ drift and v_{th} is the thermal velocity. This corresponds to fast violent instabilities, which are not seen in current experiments, where the **drift ordering** is more commonly employed.

microinstability An **instability** usually due to particle effects on the **cyclotron radius** scale.

microtearing Magnetic field fluctuations that cause small **magnetic island** chains near rational **magnetic surfaces**.

microtearing mode A mode due to **microtearing**.

migma device A fusion device that works with **non-thermal plasmas** colliding ions in a recirculating particle beam.

minimum-B configuration See **magnetic well**.

minor radius Usually denoted a, it is the distance from the **magnetic axis** to the edge of the torus. See Figure 15.

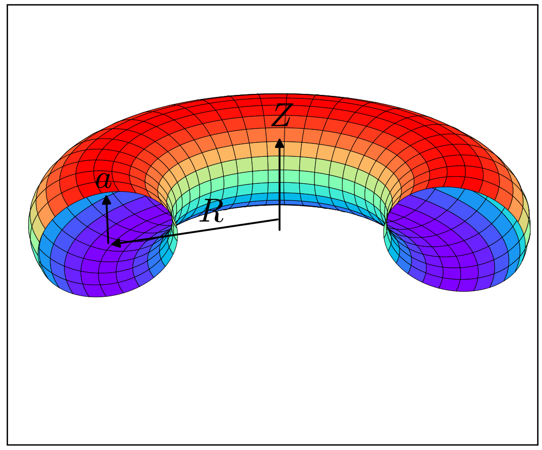

Figure 15: Showing the major radius R and minor radius a.

mirror effect The mechanism by which **magnetic mirrors** work. A particle traveling into a region where the amplitude of the magnetic field is increasing will have its velocity parallel to the magnetic field decreased. If the magnetic field is strong enough, the particle will stop its parallel motion and will "bounce" back in the opposite direction (hence a "mirror" effect). This can confine the particle.

mirror ratio This is usually denoted $r_{\text{mirror}} = R_{\text{mirror}} = B_{\text{max}}/B_{\text{min}}$. It gives a simple inequality for trapped particles, $r_{\text{min}} > \frac{v^2}{v_\perp^2}$ is true for trapped particles where v is the particle's speed and $v_\perp$ is the component of the velocity perpendicular to the magnetic field. This is sometimes reformulated as $r_{\text{min}} - 1 > v_\parallel^2/v_\perp^2$.

MKS A system with base units of meter, kilogram, and second. Electromagnetic units are not specified. Usually refers to **MKSA**.

MKSA A system with base units of meter, kilogram, second, and Ampère. This system has been superseded by **SI**.

mode conversion When a plasma wave propagates, some of its energy is excited into other plasma waves/modes.

modulus of compression See **bulk modulus**.

moment Given a function, $f(x)$, then moments are usually defined through $M_\alpha = \int \mathrm{d}x\, x^\alpha f(x)$, with α being the order of the moment. However, a moment can be an arbitrary function instead of x^α.

moment hierarchy See **statistical moment hierarchy**.

momentum This is the product of **mass** and **velocity**. Generally denoted $\mathbf{p}$, (it is not clear how this convention was chosen. Maybe from the Latin *impetus* or *pellere* or perhaps from German *Impuls* as i and m were already used, p would be the next logical choice). It has the units of kg m/s.

motional Stark effect When an atom is moving through a magnetic field, the atom in its frame of reference sees an electric field, and so its emissions will be modified by the **Stark effect**. Thus by looking at the splitting of the spectrum from the atom, one can find the magnetic field.

MSE See **motional Stark effect**.

MT See **microtearing**.

MTM See **microtearing mode**.

m

N n

N.B. Latin. Short for *nota bene* or *notate bene*. It translates as "note well" and is used to give helpful hints or as a way to record a note for the reader.

nabla The symbol ∇. Often thought of as a vector of differential operators, $\left(\frac{\partial}{\partial x}, \frac{\partial}{\partial y}, \frac{\partial}{\partial z} \right)^T$. Its name comes from a Hebrew harp which it resembles. Often called **del** or, rarely, **atled**.

neoclassical diffusion Diffusion not predicted by classical coulomb scattering theory. It is due to a toroidal shape and the gyro-motion of the particles. As the particle gyrocenters move, there is an effect on the diffusion of the particles.

n

neoclassical toroidal viscosity Often abbreviated NTV. This is the toroidal viscosity (so it usually slows down the toroidal rotation) calculated due to a breaking of the axisymmetry of the magnetic field in a tokamak (due either to magnetic perturbations or **error fields** in the tokamak). These small distortions cause the distortions of the **flux surfaces**, and these new flux surfaces are what transport properties must be calculated from, and in general causes the toroidal viscosity to be large. If the error is δB and the equilibrium magnetic field is B, then $\delta B / B \sim 10^{-4}$ in many tokamaks, but the contribution due to NTV scales as $\sqrt{\delta B / B} \sim 10^{-2}$, which can be significant. Also note that there are steady-states without toroidal momentum sources with NTV. This is because in an axisymmetric configuration the **banana orbits** and the **passing particles** orbits combine (and cancel) in such a way as to prevent toroidal and poloidal flows. When there is some non-axisymmetry, this exact cancellation is broken and so there is a poloidal/toroidal flow, similar to **diagmagnetic drift**. So the NTV can balance this flow generating mechanism.

neoclassical transport See **neoclassical diffusion**. This is transport due to a toroidal shape and the gyromotion of the particles.

net force Given many **forces** on an object, the vector addition of all these forces is the net force.

neutral beam injection (**NBI**). A way of heating a plasma by injecting fast neutrals into the plasma column that interact with ions and so through **thermalization** of the plasma, heat the plasma up.

neutralized plasma A plasma with no net charge.

Newton's dot notation The notation for **differentiation** with respect to a time variable, t. So $\frac{\mathrm{d}}{\mathrm{d}t}$ is represented as a dot over a variable, so that $\frac{\mathrm{d}f}{\mathrm{d}t} \equiv \dot{f}$.

Newton's first law An object that is subject to no forces, will either be at rest or moving at a constant velocity for all time.

Newton's laws of motion The three laws of motion attributed to Newton. They are given separately under **Newton's first law**, **Newton's second law**, and **Newton's third law**.

Newton's notation See **Newton's dot notation**.

Newton's second law The time derivative of **momentum** is the **net force** on the system. Mathematically, for momentum $\mathbf{p}$, $\frac{\mathrm{d}^2\mathbf{p}}{\mathrm{d}t^2} = \mathbf{F}_{\mathrm{net}}$.

Newton's third law Generally given as, "For every action there is an equal and opposite reaction." This definition leaves much to be desired, as **action** has changed definitions since Newton's time. A better rendition would be, All forces exist in pairs, such that in each pair, the "first" force is equal and opposite to the "second" force in the pair. For example, if object A exerts a force $\mathbf{F}_{\mathrm{A}}$ on object B, then object B exerts a force $\mathbf{F}_{\mathrm{B}}$ such that $\mathbf{F}_{\mathrm{B}} = -\mathbf{F}_{\mathrm{A}}$.

Newtonian physics See **classical physics**.

non-inductive drive A method to drive plasma current that does not involve **ohmic heating**.

non-irrotational A **vortex motion** where $\boldsymbol{\nabla} \times \mathbf{v} \neq 0$ with $\mathbf{v}$ being the flow velocity. One wonders why this was not just called rotational. If your head is "spinning" from the negatives inherent in this word, you are not alone.

non-neutral plasma A plasma that has only a single type of charged species. For example, a pure-electron plasma.

non-thermal plasma A plasma that is not in thermal equilibrium, i.e., does not have Maxwellian distribution of velocity.

normal curvature For the **Darboux frame**, this is the curvature due to being constrained to a surface. It is the "natural" curvature that is necessary for a trajectory to remain on a specified surface.

normal strain The **strain** along the straight lines of a material.

normal stress A **stress** along the unit normal of the surface of the material.

normal torsion See **geodesic torsion**.

normal vector This is a vector normal (i.e., perpendicular) to either another vector, a plane, or some other hypersurface. For the **Frenet-Serret frame**, it is defined by being perpendicular to the **tangent vector**. For the **Daroboux frame**, it is defined by being perpendicular to the constraint surface.

normalized beta This quantity is defined by $\beta_N = \beta a B_T / I_p$ where a is the minor radius in meters, B_T is the toroidal magnetic field in Tesla, and I_p is the plasma current in megaamperes. It is the **plasma beta** normalized to indicate how close one is to the Greenwald limit. $\beta_N = 2.8$ is the Troyon limit, and values above this often have problems with MHD instabilities (although $\beta_N = 3.5$ is the empirical value and higher values have been achieved).

normalized gyroradius This is the gyroradius normalized by some factor L characteristic of transport. Usually denoted $\rho^* = \rho/L$ with ρ the **gyroradius**. The characteristic length L in a tokamak is usually the **minor radius** a.

NTV See **neoclassical toroidal viscosity**.

number density This the number of particles per meter cubed (m^3). Usually denoted n_s for a particle species s. By definition, this has the relationship $n_s = \rho_s / m_s$ where ρ_s is the mass density of species s.

numerical stiffness See **stiff system**.

O o

O-point This is a point where magnetic field goes to zero, but the magnetic surfaces nearby look like a circle rather than an X.

oblate This refers to a **spheroid** that is flattened near the poles. Thus, the equatorial radius is larger than the polar radius.

Ohm's Law (1) A relationship between the current density and the electric field. Often $\mathbf{E} = \overleftrightarrow{\boldsymbol{\sigma}} \cdot \mathbf{J}$ where $\overleftrightarrow{\boldsymbol{\sigma}}$ is the conductivity tensor. In plasma physics this is often rewritten as $\overleftrightarrow{\boldsymbol{\eta}} \cdot \mathbf{E} = \mathbf{J}$ with $\overleftrightarrow{\boldsymbol{\eta}} = \overleftrightarrow{\boldsymbol{\sigma}}^{-1}$. (2) Often in electrical situations refers to $V = IR$ where V is voltage, I is current, and R is resistance.

ohmic heating Heating due to electrical resistivity. The I^2R power loss, where I is the current and R the resistance.

omnigenous A toroidal equilibrium where the magnetic field magnitude is a **flux label**. That is, $B = B(r)$. An omnigenous magnetic field has vanishing average radial drifts for a plasma.

opacity Refers to how much **attenuation** occurs as light passes through a material.

open field line A field line that is open, that is does not close on itself. (This is generally possible because field lines can trace surfaces, and some ergodically fill a volume). However, this is usually in reference to field lines outside of the main plasma and inside a device where the magnetic field line would have its endpoints on the inner surface of the confinement vessel.

open flux surface A **flux surface** that is open, that is does not close on itself. This is usually in reference to inside a device where the lines connect to the confinement vessel.

ordinary wave This is a a type of plasma wave that has a **cutoff frequency** dependent on density as can be seen in the **CMA diagram** and from its dispersion relation of $\omega^2 = k^2c^2 + \omega_p^2 = k^2c^2 + \frac{ne^2}{m\epsilon_0}$ where ω_p is the **plasma frequency**. So for $\omega^2 < \omega_p^2$, k is imaginary indicating **evanescent waves**.

outboard On a toroidal device this is the area farthest from the center or farthest from the hole, so on the "outside" of the device.

P p

palinstrophy This is gradient of the **vorticity** integrated over a region (in 2D). Or $\mathcal{P} = \frac{1}{2}\int_S \mathrm{d}S|\boldsymbol{\nabla}\times\boldsymbol{\omega}|^2$ where S is a surface to integrate over and $\boldsymbol{\omega} = \boldsymbol{\nabla}\times\mathbf{u}$ is the vorticity with $\mathbf{u}$ the flow velocity. For 2D with $\boldsymbol{\omega} = \omega\hat{\mathbf{z}}$ then $\mathcal{P} = \frac{1}{2}\int_S \mathrm{d}S|\nabla\omega|^2$, as an equivalent form.

paramagnetism The phenomenon in which a material subjected to an externally applied magnetic field will develop a magnetization in such a way that it increases the magnetic field. A material where this is the primary magnetic effect is called a paramagnetic material.

parametric instability An instability in a system that has weak oscillations in its equilibrium in either time or space.

particle A small localized object. In **classical physics**, a particle can be assigned a mass (and volume), position in space, and velocity. In other situations, it is difficult to explain exactly what a particle is, but generally a particle has physical properties and a location.

particle confinement time In **FRCs**, this its the decay time (the time it takes the value to go down to $1/e$ of its initial value) of the particles. Alternatively, given a global number of particles N, the number of particles required to be injected to keep in steady state $\mathrm{d}N_{\mathrm{in}}/\mathrm{d}t$, and $\mathrm{d}N_{\mathrm{out}}/\mathrm{d}t$ is the unavoidable particle losses then $\tau_N = N/(\mathrm{d}N_{\mathrm{in}}/\mathrm{d}t - \mathrm{d}N_{\mathrm{out}}/\mathrm{d}t)$, where τ_N is the particle confinement time. Often τ_p is used as the particle confinement time.

passing particle In plasma physics this describes paticles with small **magnetic moments** that can penetrate regions of strong magnetic field (that is, conservation of the magnetic moment does not cause them to reflect). In toroidal devices, these particles continually go around the torus in a helical pattern.

passive scalar This refers to a scalar in an equation that does not modify the velocity field (in essence, it is carried "passively" by the velocity field). For example in the equation $\frac{\partial n}{\partial t} + \mathbf{v}\cdot\nabla n = D\,\nabla^2 n$ with $\mathbf{v}$ independent of n, then n does not affect $\mathbf{v}$, so n is a passive scalar.

PDF See either **probability density function** or **probability distribution function**.

perfect conductor This is equivalent to setting resistivity ρ to zero, $\rho \to 0$. Note that this is different than a superconductor. A superconductor also has the **Meissner effect**, which expels magnetic flux from the superconductor. A perfect conductor freezes the flux that was in it at the time of the creation of the perfect conductor.

perfect crystal A **crystal** that contains no imperfections.

perfect differential A differential that is integrable. In 3D, this says that a differential can be written in the form of a gradient. That is $\mathrm{d}Q = \frac{\partial\mathbf{Q}}{\partial\mathbf{x}}\cdot\mathrm{d}\mathbf{x}$. This allows the quantity Q to be path independent. This can be generalized past scalars to vectors and tensors.

perfectly conducting wall See **ideal wall**.

permeability of free space Denoted $\mu_0 = 4\pi\times 10^{-7}$ H/m, it is a defined constant in the **SI** system of units for electromagnetic phenomena.

permittivity of free space Denoted $\epsilon_0 = \frac{1}{\mu_0 c^2} \approx 8.85\times 10^{-12}$ F/m, it is a defined constant in the **SI** system of units for electromagnetic phenomena.

PFC See **plasma facing component**.

Pfirsch-Schlüter current A current (parallel to the magnetic field) that comes about in order to neutralize current due to pressure gradients in a toroidal geometry.

phase space This is a particle's momentum/velocity components vs. a particle's coordinates in space. (Or a particle's coordinates in space vs. a particle's momentum/velocity) All possible states of a system are in phase space with each point representing a unique state.

phase velocity This is the velocity of a given phase in a medium. It is calculated as $v_p = v_\phi = \frac{\omega}{k} = \lambda\nu$ where ω is the angular velocity k is the wavenumber, λ is the wavelength, and ν is the frequency.

pinch device A device that uses the **pinch effect**. For example, the **theta-pinch** or **Z-pinch**.

pinch effect An effect where a plasma is compressed or restricted, hence "pinched". It uses that a strong current creates a magnetic field that makes particles rotate round the current such that it reinforces the current and so brings the plasma nearer to the current (hence providing more and more confinement).

pitch angle This gives the angle relative to the direction of the magnetic field, of the velocity. Calling the velocity parallel to the magnetic field $v_\parallel$ and perpendicual to the magnetic field $v_\perp$, the pitch angle is usually defined as $\alpha = \arctan\left(\frac{v_\perp}{v_\parallel}\right)$. It should be 0 when $v_\perp = 0$.

plasma An **ionized gas** that has certain collective properties. Generally three criteria, first that the **number density** inside a **Debye Sphere** is greater than 1, second, that the **Debye length** is small compared to the characteristic length of the plasma, and, third, **plasma frequency** is large compared to the electron-neutral **collision frequency**.

plasma beta See **beta**.

plasma confinement Confining a plasma within a vessel without the plasma destroying the containment vessel.

plasma discharge See **glow discharge**.

plasma dispersion function This function represents the dispersion relation for electrostatic plasmas. It is defined as $Z(\zeta) = \int_{-\infty}^{\infty} \frac{e^{-t^2}}{t-\zeta}\, dt$, and is the Hilbert transform of a Gaussian. It is defined this way for $\Im(\zeta) > 0$ and analytically continued for $\Im(\zeta) \leq 0$. The function's properties have been extensively compiled by Fried and Conte. The **Fadeeva function** is sometimes used in Russian literature.

p

plasma display Works by having a gas in between glass panels, and when the gas is electrically excited, the gas glows. This light is then routed to a pixel.

plasma elongation See **elongation**.

plasma facing component Shortened to **PFC**. Any component of a confinement device that faces the plasma, and therefore can be struck by a disrupted plasma.

plasma focus A device working on the **pinch effect** and utilizing **dense plasma focus**.

plasma frequency This is the frequency at which a plasma naturally oscillates given an excitation without a magnetic field. It is usually denoted $\omega_p = \sqrt{\frac{ne^2}{m_e \epsilon_0}}$ (SI) or $\omega_p = \sqrt{\frac{4\pi ne^2}{m_e}}$ (Gaussain) where the ions have been neglected. Sometimes it is then written as ω_{pe} and ω_p refers to the full expression.

plasma oscillations An electrostatic oscillation of the plasma near the plasma frequency.

plasma parameter Usually referred to as Λ, it is $4\pi n\lambda_D^3$ (sometimes $n\lambda_D^3$ or $\frac{4\pi}{3}n\lambda_D^3$) where λ_D is the **Debye length**. In other words, it is the number of particles in a **Debye sphere**. When $\Lambda \gg 1$ we have a true, full plasma, while for smaller Λ the ions/electrons of the plasma interact strongly with each other. A note of caution, some call $1/\Lambda$ the plasma parameter instead.

plasma physics The study of plasma characteristics, uses, and properties. It encompasses astrophysical, fusion, and some laser research and industrial applications.

plasma porthole See **plasma window**.

plasma potential See **space potential.**

plasma processing Any process that uses plasmas to etch, coat, or interact chemically with materials.

plasma sheath See **Debye sheath**.

plasma spraying Use of plasma in material processing for coating materials.

plasma transport See **transport**.

plasma turbulence See **turbulence**.

plasma valve A layer of gas in the shell of a particle accelerator. When a vacuum breach occurs, the gas is ionized into a plasma forming a **plasma window** preventing further decompression.

plasma wave Any of numerous types of waves that occur in plasmas.

plasma window This is a plasma discharge separating low pressure chambers from high pressure chambers without solid material. It can be used to separate vacuum from atmospheric pressure. It does allow radiation to pass through (such as laser light), hence a "window."

plasma-aided deposition Deposition of materials with **plasma processing** techniques

plasma-plasma reaction An interaction between two thermal ions in a plasma (not between an injected ion and plasma ion).

Plemelj formula See **Sokhotski-Plemelj formula**.

Poincaré plot See **Poincaré section**.

Poincaré section This shows a particle's trajectory (or many particles' trajectories) in some submanifold of the **phase space** of the particle by taking a particle at time t and then sampling its momentum and location periodically as t increases. Generally, if it is nearly periodic motion, then one plots for every "period." This is sometimes called stroboscopic, as it is if you were looking at the particle under a strobe light. Also known as a **Poincaré plot**, **recurrence map**, **surface of section**, **puncture plot** or **Poincaré map**. See Figure 16 for an example.

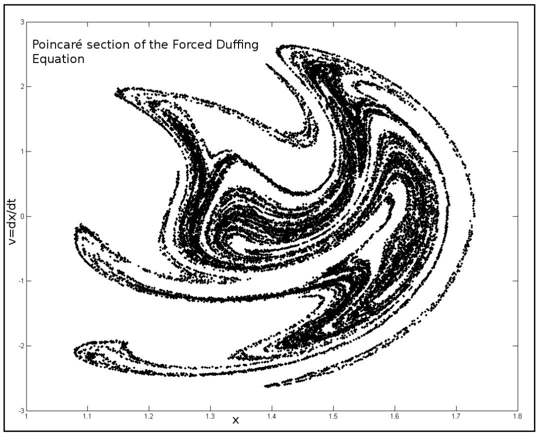

Figure 16: Poincaré section for the Duffing equation $\ddot{x} + \delta\dot{x} + \alpha x + \beta x^3 = \gamma\cos(\omega t)$. This image is from Wikipedia by JJ Harrison with a CC-3.0 license.

Poisson bracket This is usually denoted $\{\cdot, \cdot\}$ and is defined such that $\{f\,,\,g\} = \frac{\partial f}{\partial q_i}\frac{\partial g}{\partial p_i} - \frac{\partial f}{\partial p_i}\frac{\partial g}{\partial q_i}$ where the **Einstein summation notation** has been employed. The q_i and p_i are the **canonical coordinates** for the particular system. It can be used to test **canonical transformations**.

Poisson constant See **adiabatic index**.

Poisson's ratio The amount of change in length per unit length of a transverse segment. This is a constant where **Hooke's law** applies and is often called σ.

polar vector This is a normal or **true vector**. It does not change signs under rotation, but does under so reflection of coordinates.

polarization (1) Referring to **polarization density**. (2) The direction the **electric field** points in an electromagnetic wave. (3) For spin polarization, the direction of a spin (4) In electrochemistry, a change in equilibrium potential of an electrochemical reaction.

polarization density This is average **electric dipole moment** per unit volume of a material. If N particles in a volume V all have electric dipole moment $\mathbf{d}$, then the polarization density is $M = N\mathbf{d}/V$.

polhode Imagine an ellipsoid on a fixed plane. As the ellipsoid rolls on the plane, the point of contact between the fixed plane and the ellipsoid will draw a curve on the ellipsoid. This is the polhode. More generally any object on a fixed plane. See Figure 8.

poloidal beta See **(poloidal) beta** under B.

poloidal direction This is the "short way" around a torus. Concretely, if you put one finger through a bagel and touched your thumb, that circle made by your finger and thumb would have its circumference run in the poloidal direction of the torus. See Figure 17.

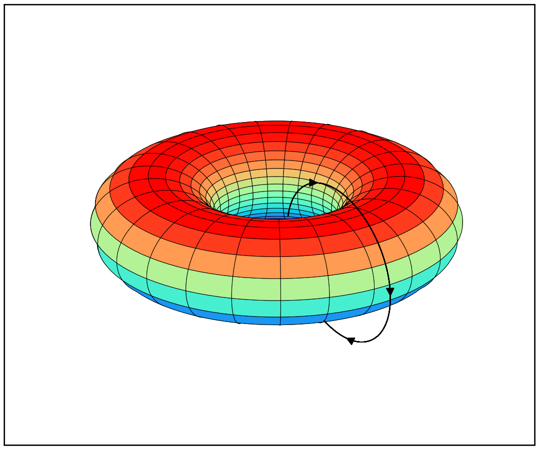

Figure 17: Poloidal direction along a torus.

poloidal flux This is magnetic flux through a surface due to poloidal magnetic field. It is usually measured as a **ribbon flux** (sometimes denoted ψ_r where the surfrace runs from the **magnetic axis** out to some **flux surface** radius, or as a **disk flux** (sometimes denoted ψ_d where the surface is a disk centered around the **geometric axis** (usually midway through the torus in the Z direction) in the standard R-ϕ plane in standardly used tokamak cylindrical coordinates. Poloidal flux is often denoted Ψ_p, Ψ_P or ψ_p, ψ_P and defined as $\Psi_P = \int_{S_P} \mathrm{d}S\ \hat{\mathbf{n}} \cdot \mathbf{B}$ with S_p a poloidal ribbon surface, and $\hat{\mathbf{n}}$ the outward normal of the surface. Alternatively, $2\pi\Psi_P = \int_{V(r)} \mathrm{d}^3x\ \mathbf{B} \cdot \nabla\theta$ where $V(r)$ is the volume enclosed by the flux surface on surface r and θ is the poloidal angle variable. See figure 18 for the ribbon flux.

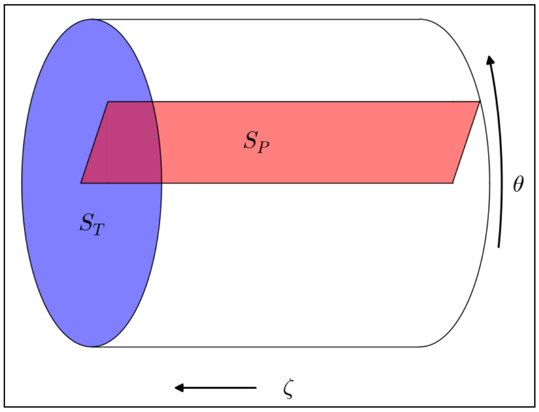

Figure 18: Poloidal surface S_p (a ribbon surface) and toroidal surface S_T for poloidal and toroidal flux.

poloidal mode number When a quantity in a tokamak $F(r, \theta, \zeta)$ with the usual convention (r is a radial coordiante, θ is a poloidal coordiante, and ζ is a toroidal coordinate) is decomposed into $F(r, \theta, \zeta) = \sum_{m=0}^{\infty} \widetilde{F}(r, \zeta) e^{im\theta}$, the m is the poloidal mode number. The specific letter m is conventionally used as the poloidal mode number variable.

potential energy This is energy associated with either the position of a particle or its organization of particles.

Prandtl number A dimensionless number of fluid mechanics usually denoted $\mathrm{Pr} = \frac{\nu}{\kappa}$ where ν is **kinematic viscosity** and κ is thermal diffusivity. It can be interpreted as $\frac{\text{viscous}}{\text{thermal}}$ diffusion.

prime notation See **Lagrange's prime notation**.

principal stresses The diagonal terms of the diagonalized **stress** tensor.

principal value See **Cauchy principal value**.

principle of least action See **Hamilton's principle**.

p

private flux region Usually denoted **PFR**. This is the closed field line region in a **divertor** configuration toroidal plasma confinement device that is not where the main plasma is.

probability density function This is the function that when integrated through a range of values, gives the probability of that range of values occurring.

probability distribution function For a continuous variable, this is the probability density function (in most cases). For a discrete variable, this is usually the probability of the function taking a value.

prolate This refers to a **spheroid** that is flattened near the equator. Thus, the equatorial radius is smaller than the polar radius.

proper function See **eigenfunction**.

proper value See **eigenvalue**.

proper vector See **eigenvector**.

pseudoscalar A scalar quantity that switches sign upon (reflections) [Newtonian] or (Lorentz transformations or space-time transformations) [relativity]. It can be described by a number (although it may be a complex number).

pseudovector See **axial vector**.

puncture plot See **Poincaré plot**.

Q q

Q In plasma physics, this is denoted Q and refers to the energy out over the external heating put in. Then $Q > 1$ means more energy comes out of the process than external heating energy is put in. Physicists' Q only counts the heating energy directly coupled into the plasma. Engineering Q counts all of the energy required to create that heating energy in addition and so is strictly smaller than physicists' Q. A **burning plasma** has physicists' $Q \gtrsim 5$ and an ignited plasma has $Q = \infty$ since no external heating is required.

q In plasma physics, this is usually the **safety factor**.

QED Latin. Short for *quod erat demonstrandum*. It translates as "that which was to be demonstrated" and is used to denote the ending of a proof.

qiviut The wool of the undercoat of the musk-ox. (Here strictly for educational purposes with regard to there existing non "qu" words in English.)

QSH See **quasi-single-helicity**.

quantum mechanics Physics that deals with the fact that some quantities (energy, angular momentum, etc.) are quantized, i.e., they come in discrete amounts rather than vary continously.

quantum physics See **quantum mechanics**.

quark-gluon plasma A state for quarks in gluons at high temperatures where the color charge is screened just as for a "regular" plasma, the electric charge is screened.

quasi-single-helicity regime A regime in an **RFP** where a single dominant helical mode spontaneously occurs when at high **Reynolds number**.

quasigeostrophic beta plane model A model in atmospheric science that can be used to understand **Rossby waves**. A **beta plane** is a local latitute and longitude on Earth stretched into an xy plane (x is the East-West direction and y is the North-South direction). It also adds in an effect due to the Coriolis effect proportional to β (hence the name). Here quasigeostrophic is referring to Coriolis and pressure gradient forces nearly balancing, but inertial forces also contributing.

quasilinear theory A nonlinear theory (that uses some linear theory quatnities) of plasma evolution that uses perturbations and random phase to predict time evolution.

quasineutral plasma A plasma in which the total charge of the plasma is basically zero. This does not mean that Gauss's law is completely satisfied, but it is very small so that there are very small electrostatic fields rather than no electrostatic fields. This can be quantitatively checked as the forces due to electrostatic fields are small compared to the other forces acting in the plasma.

quasinormal closure This is a closure for a **statistical moment hierarchy** that involves treating fluctations as Gaussian at the fourth-order moment, but not at the third-order moment. (A Gaussian's fluctuation moments past second-order generally vanish).

quiescent A state of rest or inactivity in some process.

R r

radiative collapse An instability in **Z-pinch** devices. When power lost due to radiation (line radiation and bremsstrahlung) is more than **ohmic heating**. The plasma temperature falls and the collaspses inward radially.

radiative condensation instability Plasmas which cool through radiation become unstable due to regions of increased density and lower temperature.

radio frequency current drive Method of forming plasma currents for plasma heating through plasma waves.

radio frequency heating Method of plasma heating through plasma waves.

radius of curvature Usually denoted R. For a given point on a curve, it is the radius of a circle whose arc best approximates the curve at that point.

Raman effect See **Raman scattering**.

r

Raman scattering An effect in which light scattering through a transparent medium has a frequency change and a random change of phase because of the change in vibrational or rotational energy of the scattering molecules.

ratio of specific heats See **adiabatic index**.

rational surface In a plasma, this refers to a **magnetic flux surface** characterized by a **safety factor** (or **rotational transform**) that is in the form $q = \frac{m}{n}$ where m and n are both integers.

Rayleigh number A dimensionless number of fluid mechanics associated with the buoynacy force in a fluid. It is usually denoted $\mathrm{Ra} = \frac{g\beta\Delta T\, d^3}{\kappa\nu}$ where g is **standard gravity**, β is the **volumetric expansion coefficient** defined by $\frac{\mathrm{d}V}{V} = \beta\,\mathrm{d}T$, ΔT is the temperature difference, d is the characteristic length, κ is the **thermal diffusivity**, and ν is **kinematic viscosity** and can be interpreted as $\mathrm{Ra} = \frac{\text{buoyancy}}{\text{diffusion}}$ forces. Above a threshold Rayleigh number value **convection** dominates heat transfer and below the threshold **conduction** dominates heat transfer.

Rayleigh-Taylor instability A **hydrodynamic instability** arising from the interface between two different density fluids. For example, a denser fluid being above a lighter fluid under the influence of gravity. The heavier fluid will slowly go through the lighter one to be on the bottom, or if you prefer, the lighter fluid goes through the heavier fluid to get to the top.

reciprocal vector basis Given a vector basis $\mathbf{v}_i$, then the reciprocal vector basis $\mathbf{w}_j$ satisfies $\mathbf{v}_i \cdot \mathbf{w}_j = \delta_{ij}$.

reconnection See **magnetic reconnection**.

recurrence map See **Poincaré section**.

resistive instaility Instabilities that occur in resistive MHD, but not in ideal MHD theory.

resistive MHD A theory of MHD which includes resistive effect. Usually by adding in resistivity to the **Ohm's law**. $\mathbf{E} = -\mathbf{v} \times \mathbf{B} + \eta\mathbf{J}$.

resonance In waves, a resonance occurs when $k, n \to \infty$ (k is the **wavenumber**, and n is the **index of refraction**). This is usually associated with energy in the wave being transferred to particles, especially at so-called cyclotron-resonances which occur at, or integer multiples of, the **cyclotron frequency** of the particles.

resonant magnetic perturbation Magnetic field perturbations used to control **ELM**s. Confusingly the terminology is used for many magnetic perturbations even if they are not resonant.

return current Current along the magnetic field that neutralizes charge accumulated by perpendicular current density. It is made up of **bootstrap current** and **Pfirsch-Schlüter current**.

reversed field pinch Usually shortened to RFP. A type of toroidal confinement device that is so called because it has the toroidal component of the magnetic field, $\mathbf{B}_T$, reverse direction inside the confinement region.

Reynolds number A dimensionless number of fluid mechanics measuring how important **turbulence** is in the system. It is usually denoted Re, and $\mathrm{Re} = \dfrac{\rho L v}{\eta} = \dfrac{VL}{\nu}$ where ρ is the density of the fluid, L is the characteristic length the fluid travels, η is the **dynamic viscosity**, and ν is the **kinematic viscosity**. Note that it measures $\frac{\text{inertial}}{\text{viscous}}$ forces.

RFP See **reversed field pinch**.

RFX Short for **Reversed Field eXperiment**. An **RFP** experiment in Padua, Italy.

ribbon flux A **poloidal flux** where the poloidal surface is measured from the magnetic axis to some flux surface. See figure 18.

right circularly polarized wave A type of wave allowed in plasmas that is right-handed in the sense that having your thumb on your right hand point in the direction of propagation you would find the polarization curls as your fingers do.

rigid body A material that suffers no deformation (externally or internally) when forces are applied to it.

ripple The ripple can roughly be given by $\delta = (R/R_{\text{outer}})^N + (R/R_{\text{inner}})^N$ with R the **major radius coordinate**, and R_{inner} and R_{outer} the major radii of the outer and inner legs of the toroidal field coils, respectively. It is a measure of how much variation there is in the magnetic field when following a magnetic field line. To get the actual ripple, sometimes denoted ϵ_{eff}, one must do a more complicated calculation over field lines on flux surfaces. Ripple is important because transport is affected, with particles (most often banana orbiting particles with the "tip" of the banana at an edge of a "ripple well") sometimes becoming trapped in these small "ripple wells". For tokamaks, 2% at the edge and 0.01% at the core are generally considered the maximum amount of ripple to be allowed. The diffusion coefficient due to ripple has the relationship $D \sim \delta^{3/2}$. Note that ripple is used in electrical engineering with a completely different definition.

RMP See **resonant magnetic perturbation**.

Rossby waves These are planetary waves that occur in the atmosphere and oceans of planets. They are due to shear in rotating fluids. On Earth, the **Coriolis effect** provides the shear at different latitudes. They have a number of interesting properties, such as the **phase velocity** always has a westward component on Earth.

rotational transform A measure of the number of toroidal transits over the number of poloidal transits of a field line around a torus. Usually denoted ι or more correctly, $\iota\!\!\!-$, it is the inverse of the **safety factor**, and is usually approximated well by $\iota\!\!\!- = \frac{RB_P}{rB_T}$ while $\iota = \frac{2\pi RB_P}{rB_T}$. Because the bar in $\iota\!\!\!-$ is often omitted, sometimes $\iota = \iota\!\!\!-$.

r

S s

safety factor Denoted q and for a toroidal device $q = \lim_{\Theta\to\infty} \frac{1}{\Theta}\int_0^\Theta \frac{\mathbf{B}\cdot\nabla\zeta}{\mathbf{B}\cdot\nabla\theta}\,\mathrm{d}\theta \approx \frac{rB_\mathrm{T}}{RB_\mathrm{P}}$. Qualitatively, the number of poloidal transits over the number of toroidal transits of a field line around a torus. Also note it is the inverse of the **rotational transform**, $\iota\!\!\!{-}$.

Saha equation The thermodynamic equilibrium distribution of ions for the case of the radiation field being in equilibrium with ions and electrons.

Saha-Boltzmann equation See **Saha equation**.

Saint Elmo's Fire A type of electric discharge. It occurs because of the point of a pointed object concentrating the electric field at the point and causing ionization. It is named so because sailors saw the "fire" at the mast of the ship as a plasma glow.

saturation current The limiting current when a voltage is applied to a cathode/anode. That is, as one increases the voltage, one finds that at some point the current remains unaffected.

sausage mode This is a $m = 0$ MHD **interchange instability** that is called a sausage mode because the instability causes the plasma to look like a string of sausages.

sawtooth The plasma parameters, n, T, and $|\mathbf{B}|$, are observed to oscillate in a pattern that looks like the teeth in a saw.

scalar A scalar is quantity unchanged by certain coordinate changes (such as rotations and reflections, or Lorentz transformations and space-time transformations). It can be described by a number (although it may be a complex number).

scalar potential This is a scalar valued function that when the negative gradient is taken, yields a conservative force. That is for scalar potential U, $-\nabla U = \mathbf{F}$ for $\mathbf{F}$ a **conservative force**. It means that the potential (energy) between two points depends only on position, and not the path taken.

scrape off layer Also known as **SOL**. The outer layer of a magnetically confined plasma, such that there are **open field lines** in this region. So-called because when the magnetic field lines come in contact with a material surface they can "scrape off" the outer layer of the plasma, as particles follow the field lines into the material surface.

screw pinch A type of magnetic confinement device which is similar to a **theta pinch** and **Z pinch**. It has poth a poloidal and toroidal magnetic field so that it has a corkscrew like configuration.

second law of thermodynamics The **entropy** of an **isolated system** can never decrease. In symbols, $\Delta S \geq 0$.

second stability regime For **ballooning modes**, this refers to the fact that when comparing normalized **magnetic shear**, s, and normalized pressure gradient $\widetilde{\beta}'$, that there are two distinct regions of stability: one for small pressure gradient and one for large pressure gradient. The second stability regime is for large pressure gradient and important for constructing an economical tokamak fusion reactor. See figure 19.

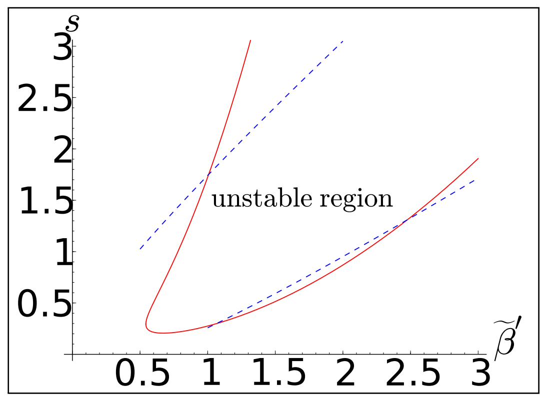

Figure 19: Regions of instability and stability for ballooning modes with normalized shear s versus normalized pressure gradient $\widetilde{\beta}'$. The solid red line is for weak ballooning and small shear, while the dashed blue lines are for strong ballooning and strong shear.

secondary electron emission The ejection of an electron from a solid or liquid by impact of an incident particle.

semi-collisional regime This is a regime for tearing modes where tearing mode frequency and growth rate are small compared to the local **collision frequency**, and specifically that $x_* \ll w$ but $\omega \ll \nu$ where $x_* = |\omega/(k_\parallel' v_{\mathrm{th}_e})|$ represents the width of the conductivity and ω represents the width of the boundary layer for the tearing mode, ν is the collision frequency, and $k_\parallel'$ is the radial derivative of the wavenumber along the magnetic field with v_{th_e} the electron **thermal velocity**. This is a regime where even though $\nu \gg \omega$, there exists a **current channel** due to long **mean free path**.

separatrix In phase space, there are closed lines and open lines. The separatrix is the boundary between these two types. In plasma physics, for magnetic field lines there are two types in a **divertor** configuration, the lines going out to the divertor and the regular field lines for confinement (and those in the **private flux region**). The separatrix is the divider for these two types.

sequence An ordered list of elements in some space.

SHAx See **single helical axis**.

shear The shear of a vector field $\mathbf{V}$ is generally given by $\frac{1}{2}\left(\nabla V + (\nabla V)^{\intercal}\right) - \frac{1}{3}\boldsymbol{\nabla}\cdot\mathbf{V}$ with $\intercal$ meaning transpose. Note this is the **symmetric tensor** part of ∇V minus the trace. For a magnetic field in the Darboux frame with binormal unit vector $\hat{\boldsymbol{\eta}} = \hat{\mathbf{n}} \times \hat{\mathbf{b}}$ where $\hat{\mathbf{n}}$ is the unit surface normal and $\hat{\mathbf{b}}$ the unit magnetic field vector, the magnetic shear vector is $\hat{\boldsymbol{\eta}} \cdot \boldsymbol{\nabla} \times \hat{\boldsymbol{\eta}}$.

shear Alfvén law A law introduced by Hazeltine and Meiss in *Plasma Confinement* that governs low frequency dynamics of plasma. It is given by

$$\mathbf{B}\cdot(\boldsymbol{\nabla}\times\mathbf{f}) = B^2\mathbf{B}\cdot\nabla\left(\frac{J_\parallel}{B}\right) - \frac{\mathbf{B}\times\boldsymbol{\kappa}}{\mu_0}\cdot\nabla_\perp B^2$$

$$\mathbf{f} = \rho_m\frac{\mathrm{d}\mathbf{V}}{\mathrm{d}t} + \boldsymbol{\nabla}\cdot\overleftrightarrow{\boldsymbol{\Pi}}$$

$$\nabla_\perp B^2 = \frac{1}{B^2}\mathbf{B}\times\left(\nabla B^2\times\mathbf{B}\right)$$

where $\mathbf{B}$ is the magnetic field, $B = |\mathbf{B}|$, $J_\parallel = \mathbf{J}\cdot\mathbf{B}/B$ is the parallel current, ρ_m is the mass density, $\overleftrightarrow{\boldsymbol{\Pi}}$ is the **gyroviscosity** and $\boldsymbol{\kappa}$ is the **curvature vector**. Sometimes it is written as (this form is called the **vorticity** equation)

$$\mathbf{B}\cdot(\boldsymbol{\nabla}\times\mathbf{f} - 2\boldsymbol{\kappa}\times\mathbf{f}) = B^2\mathbf{B}\cdot\nabla\left(\frac{J_\parallel}{B}\right) + 2\mathbf{B}\times\boldsymbol{\kappa}\cdot\nabla p$$

with ∇P the pressure gradient. In this form, we see that the left hand side is plasma inertia while the right hand side is driving forces.

shear modulus This describes how stiff an object is to a **shear stress**. It is given by $\frac{E}{2(1+\sigma)}$ with E **Young's modulus** and σ **Poisson's ratio**.

shear rate This is the rate at which a shearing deformation is applied. Denoting the shear rate for a particular direction as s_{ij} then $s_{ij} = \frac{\partial v_i}{\partial x_j} + \frac{\partial v_j}{\partial x_i}$ with v_i a velocity component. Thus, in vector/tensor notation $\overleftrightarrow{\mathbf{s}} = \nabla\mathbf{v} + (\nabla\mathbf{v})^{\intercal}$. See also **shear**.

shear strain The component of strain that is perpendicular to two particles in a line. That is it measures how two lines that were once perpendicular in the material now have a different angle between them after the deformation.

shear stress This occurs when there is a force parallel to the cross section of the material.

sheared field In plasma physics this refers to having a changing **safety factor** (amount of turning of magnetic field) as the radius is varied. Generically it refers to a vector field that rotates and so has nonzero shear. See **shear**.

sheath See **plasma sheath**.

sheath dissipation model This is a model that assumes that **filaments** are sheath connected, i.e., they extend in the **SOL** from target to target (one side of limiter/divertor to the other) with negligible parallel gradients of density and electrostatic potential.

shock tube A gas filled tube that quickly ionizes a gas. A capacitor bank is discharged into the gas creating a shock wave.

shock wave A wave produced by a suddent violent disturbance.

SI See **International System of Units**.

single-helical-axis In an **RFP**, a state with only one helical axis, as opposed to multiple helical states. It occurs after a **DAx**, and elminates the original magnetic axis forming a single helical magnetic axis associated with the **QSH** helical mode.

snakes Long lived helical density perturbations in **toroidal magnetic confinement** configurations. So named, because they look like a snake when plotted in a 3D represenetation.

snowflake divertor A type of **divertor** that introduces a 2nd order null at the core **X-point**. This means that particles travel longer on field lines and so are colder when they hit the divertor plate. Sometimes used for any advanced divertor concept.

Sokhotski-Plemelj formula For integrals along the real line, it states that $\lim_{\epsilon\to 0^+}\int_a^b \frac{f(x)}{x\pm i\epsilon}\,\mathrm{d}x = \mp i\pi f(0) + ⨍_a^b \frac{f(x)}{x}\,\mathrm{d}x$ where $⨍$ indicates the **Cauchy principal value**. The more general form is of less use in physics.

SOL See **scrape off layer**.

solar corona The corona is an outer layer of the sun's atmosphere that is much hotter than the surface (5500 K) at about 1 million kelvin. It is a hot low density plasma.

solar filament A large bright feature extending out of the sun. Also known as a solar prominence.

solar prominence See **solar filament**.

solar wind A mostly hydrogen plasma that blows out of the **solar corona**. It is a stream of highly charged particles.

solenoidal field A **vector** field is considered solenoidal if the **divergence** of the vector field is zero. Hence for vector field $\mathbf{A}$, a solenoidal $\mathbf{A}$ satisfies $\nabla \cdot \mathbf{A} = 0$.

soliton A nonlinear wave that does not disperse as it travels. One example are solutions to the Korteweg-de Vries equation.

sound speed This is the speed of sound in a material. In a plasma, this usually is referred to as $c_s \cong \sqrt{(k_B T_e + k_B T_i)/(m_i + m_e)} \approx \sqrt{(k_B T_e + k_B T_e)/m_i}$ with $T_{i,e}$ a (ion/electron) temperature, $m_{i,e}$ the (ion/electron) mass, and k_B the Boltzmann constant.

space (1a) The universe outside of Earth's atmosphere. (1b) [commonly in physics] this refers to the region of the universe outside of Earth's atmosphere but within the Sun's (appreciable) gravitational pull (2) An abstract physical property that gives meaning to the question "where is something" which is sometimes extended to include time so that "when is something" is also given meaning. (3) (Mathematically) A set with some added structure.

space charge A net charge in the plasma. By applying an external electric field, a net charge is often created in the plasma.

space potential The electric potential of a plasma without any probes.

space weather The state of the ionosphere and magnetosphere of the earth. It is often disturbed by the solar wind.

specific heat capacity The specific heat capacity at constant pressure or volume is usually denoted c_P or c_V, respectively. Sometimes when context makes it obvious which it is, it is just c. It is measured in J/(kg K), and is a measure of how much the temperature of a substance changes due to the input or loss of heat energy per kilogram. Usually used in $Q = mc\Delta T$ where Q is the heat, m is the mass of the substance, and T is the temperature in Kelvin.

speed In physics this means the magnitude of the **velocity**. Sometimes, colloquially, referring to a velocity, but strictly speaking this is an abuse of the term.

spherical tokamak Often shortened to ST. This is a low **aspect ratio** tokamak. It looks like a cored apple. Not to be confused with a **spheromak** which has no center post with a transformer going through it (or "cored" part).

spheroid This is an **ellipsoid** of rotation, that is it's equation can be written as $(x^2 + y^2)/a^2 + z^2/c^2 = 1$. There are two varieties with $a > c$ being **oblate** and $c > a$ being **prolate**.

spheromak A type of **FRC** that has a toroidal magnetic field component. Not to be confused with a **spherical tokamak**.

Spitzer conductivity This is the inverse of **Spitzer resistivity**, $\sigma = \frac{1}{\eta}$ where η is the Spitzer resistivity and σ is the Spitzer conductivity. See **Spitzer resistivity** for more.

Spitzer resisitvity A scaling for perpendicular resistivity of a plasma due to Coulomb collisions between ions and electrons. It is given by $\eta_\perp \sim 1.03 \times 10^{-4} Z \ln \Lambda T^{-3/2}$ with Z the charge, $\ln \Lambda$ the **Coulomb logarithm**, and T the temperature in eV. More generally it is given by $\eta = \alpha_e \frac{m_e \nu_e}{n_e e^2}$ with α_e a multiplication factor determined by the ions usually set to 0.5 for protons, ν_e is the electron **collision frequency**, n_e is the electron **number density**, m_e is the electron mass, and e is **elementary charge**. This is named after plasma physicist Lyman Spitzer.

standard gravity This is usually denoted g, g_0 or g_n, and is defined to be 9.80665 m/s^2, approximately the strength of gravity at sea level.

Stark effect The splitting of lines in the light spectrum of atoms due to weak electric fields removing degeneracies of electron states.

stationary point In calculus, a stationary point is a local minimum or maximum of a function.

statistical moment hierarchy A system of equations, usually for a **distribution function** made from taking moments (usually integrals with the distribution function multiplied by a polynomial) of the distribution function. Often requires a **closure**, as each moment depends on the next higher order moment.

steady-state The dynamics when time changes are negligible (i.e., $\frac{\partial f}{\partial t} = 0$ for an arbitrary function f.)

stiff system This is a system (of equations) where some numerical methods are numerically unstable. They are distinguished by the fact that one needs very small time steps even when the solution is very smooth and not changing rapidly. That is a system is called stiff when the time step must be small even when there is little to no variation in the solution. Note that this is a property of the system/equation, and not the exact solution. It says that the system has terms that can cause a lot of variation in the (approximate) solution.

stiffness See **stiff system**.

strain A meaure of the deformation of a material. Is a **tensor** in general.

stream function A function that allows plotting of **streamlines**.

S

streamlines For a **flow velocity**, these are individual particle trajectories in **steady-state**.

stress A force along the surface of some object that can be either perpendicular to the surface normal (**shear stress**) or along the surface normal (**normal stress**).

Super X-divertor Similar to an **X-divertor** but with the divertor moved far from the plasma (significant portion of a **minor radius** away).

surface of section See **Poincaré section**.

surface tension The force that tends to keep the shape of a liquid and resists changing shape. It is more important for small volumes of substances.

symmetric tensor A tensor whose **transpose** is equal to itself, i.e., $T_{ij} = T_{ji}$ for the tensor $\overleftrightarrow{\mathbf{T}}$. Often denoted as $\overleftrightarrow{\mathbf{T}}^{\mathsf{T}} = \overleftrightarrow{\mathbf{T}}^{\mathrm{T}} = \overleftrightarrow{\mathbf{T}}^{T}$.

symplectomorphism See **canonical transformation**.

T t

TAE See **toroidicity induced Alfvén eigenmodes**.

tangent basis vector See also **covariant basis vector**. Given a position vector $\mathbf{x} = x^0\hat{\mathbf{x}} + x^1\hat{\mathbf{y}} + x^2\hat{\mathbf{z}}$ and curvilinear coordinate system $\xi^i(x^i)$, then the tangent basis vectors are usually denoted $\mathbf{e}_i$ (with a subscript) given by $\mathbf{e}_i = \frac{\partial \mathbf{x}}{\partial \xi^i}$. Note how $\hat{\mathbf{e}}_i$ points along ξ^i and so is "tangent".

tangent vector For the **Frenet-Serret frame** and **Darboux frame**, the tangent vector is the vector that points along a trajectory. If one parameterizes a trajectory with s the arclength, then $\frac{\mathrm{d}\mathbf{x}}{\mathrm{d}s}$ for $\mathbf{x}$ the position is the tangent vector.

tangent-reciprocal basis vector See also **contravariant basis vector**. Given a position vector $\mathbf{x} = x^0\hat{\mathbf{x}} + x^1\hat{\mathbf{y}} + x^2\hat{\mathbf{z}}$ and curvilinear coordinate system $\xi^i(x^i)$, then the tangent-reciprocal basis vectors are usually denoted $\mathbf{e}^i$ (with a superscript) given by $\mathbf{e}^i = \frac{\partial \xi^i}{\partial \mathbf{x}} = \nabla \xi^i$. The tangent-reciprocal basis vectors are the **reciprocal vector basis** set for the tangent basis vectors.

t

tautology A statement which is always true regardless of circumstances. For example, if you have premise statement A, and conclude A, then A is tautologically true in this argument.

tearing mode These are waves/instabilities that form in resistive plasmas due to **reconnection** of magnetic field lines. That is, they are modes associated with changing of the magnetic field topology. They are, specifically, the even (spatial) parity **eigenmodes**.

TEM Either in plasma physics (1) **trapped electron mode** or more generally in physics (2) **transmission electron microscope** or **transmission electron microscopy**.

tensile modulus See **Young's modulus**.

tensile strain A **normal strain** that tends to incresase the length of the material along a certain direction.

tensile stress A **normal stress** that tends to pull apart the material (an "outward" force).

tensor A quanitity that describes linear relations between vectors, scalars, and other tensors. A rank of a tensor describes its **contravariant** and **covariant** components. A rank $m+n$ type (m,n) tensor denoted $T^{i_1\cdots i_m}_{j_1\cdots j_n}$. There are a large number of notations for tensors. For rank two, common notations are $\overset{\leftrightarrow}{\mathbf{T}}$, $\vec{\vec{\mathbf{T}}}$, and $\underline{\underline{\mathbf{T}}}$. For higher ranks, the index notation is generally used, although the line notation is common up to rank 3 (all of these non-index notations fail to show contravariant and covariant components since they refer to the tensor abstractly). The entry on **tensor field** gives the transformation property.

tensor ellipsoid A **symmetric tensor** of 3 dimensions can be visualized by an ellipsoid, as both have 6 independent quantities associated with them. That is for the tensor, T, the quantities $T_{11}, T_{12}, T_{13}, T_{22}, T_{23}$, and T_{33}. For the ellipsoid, it is the coefficients of x^2, y^2, z^2, xy, xz, and yz, with the surface equal to 1 (i.e., $\sum_{i,j=1}^{3} a_{ij}x_ix_j = 1$ with x_i being x, y, z for $1, 2, 3$ respectively.)

tensor field A field where every point in space is assigned a tensor. Given coordinates $(x^1, \ldots, x^k)$ and transformed coordinates $(\xi^1, \ldots, \xi^k)$, a tensor field transforms as $\hat{T}^{i_1\ldots i_m}_{j_1\ldots j_n}(\xi^1, \cdots, \xi^k) = \frac{\partial \xi^{i_1}}{\partial x^{\ell_1}} \cdots \frac{\partial \xi^{i_m}}{\partial x^{\ell_n}} \frac{\partial x^{h_1}}{\partial \xi^{j_1}} \cdots \frac{\partial x^{h_n}}{\partial \xi^{j_n}} T^{\ell_1,\ldots \ell_m}_{h_1\ldots h_n}(x^1, \cdots, x^k)$.

test particle Given a configuration of particles, it is often good to know what would happen to a particle introduced into the system hypothetically which does not affect any of the other particles; it is only affected by all the other particles. This hypothetical particle is called a test particle.

thermal conduction This is transfer of heat by collisions of particles.

thermal plasma A plasma that is in thermodynamic equilibrium. It is goverened by the **Saha equation**.

thermal speed For a particle species s, with temperature T_s, and mass m_s this is defined as $v_{\mathrm{th}_s} = \sqrt{2k_BT_s/m_s}$ with k_B the Boltzmann constant. This is the normalizing velocity for the exponent in a Maxwellian distribution. Note some sources instead define the thermal velocity as $v_{\mathrm{th}_s} = \sqrt{k_BT_s/m_s}$.

thermalization When particles go to their Maxwellian distribution, they are said to have thermalized as they have reached statistical mechanical equilibrium. This process usually involves slowing down of fast particles down to the thermal speeds.

thermodynamic equilibrium A state where there is no net flows of matter or energy.

thermodynamics The theory accounting for how heat, energy, and work are related. Derivable from **statistical mechanics**.

thermonuclear fusion Fusion reactions that occur by heating the fuel into a plasma so that colliding ions undergo fusion.

theta-pinch Or θ-pinch. A cylindrical device that has current in the θ direction. It has excellent stability, but poor confinement properties.

third law of thermodynamics There are numerous forms. (1) There is no process which in a finite number of steps can take a system to **absolute zero**. (2) The entropy of a **perfect crystal** at absolute zero is exactly zero. (3) The entropy change associated with any condensed system undergoing a reversible isothermal process approaches zero as temperature approaches absolute zero, where condensed system refers to liquids and solids. (4) The entropy of a system approaches a constant value as the temperature approaches absolute zero.

three-body recombination An atomic process in a high-density plasma where two electrons or an ion and an electron interact near an ion resulting in a recombination of the electron and ion with the third particle carrying away the rest of the energy.

tokamak A toroidal confinement device that uses external coils to create a large azimuthal magnetic field, which induce currents which create the confining poloidal fields.

topology A field of mathematics that deals with the shapes of objects disregarding continuous deformations such as bending or stretching, but not tearing or gluing. Colloquially used for plasma physics as the shape of magnetic field lines under such continuous deformations. That is, the "shape" of the magnetic field lines, including stretching or bending to the same shape.

toroidal direction This is the "long way" around a torus. If you were to cut a bagel in half by going around the hole, (so the bagel would be sliced like it usually is) then you would be cutting along the toroidal direction. See figure 20.

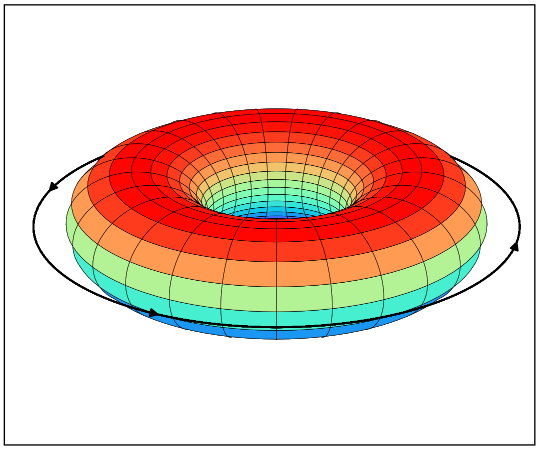

Figure 20: Toroidal direction along a torus.

toroidal field ripple Also known as TF ripple. See **ripple**.

toroidal flux A **magnetic flux** with the surface oriented so as to have a circular cross-section of the torus so that measures only toroidal magnetic field. It is often denoted as Ψ_T and defined by $\Psi_T = \int_{S_T} \mathrm{d}S\ \hat{\mathbf{n}}\cdot\mathbf{B} = \int_{V(r)} \mathrm{d}^3x\ \hat{\mathbf{B}}\cdot\nabla\zeta$ where S_T is the toroidal surface, $V(r)$ indicates the volume enclosed by flux surface r and ζ is the toroidal angle variable. See figure 18

toroidal magnetic confinement A magnetic confinement scheme where the confinement is done through a toroidal configuration of the confinement region. That is, the problem of particles exiting a cylinder is solved by closing the cylinder on itself into a torus.

toroidal mode number When a quantity in a tokamak $F(r,\theta,\zeta)$ with the usual convention (r is a radial coordiante, θ is a poloidal coordiante, and ζ is a toroidal coordinate) is decomposed into $F(r,\theta,\zeta) = \sum_{n=0}^{\infty} \widetilde{F}(r,\theta)e^{-in\zeta}$, the n is the toloidal mode number. The specific letter n is conventionally used as the toloidal mode number variable.

toroidal-pinch A device that is like a **Z-pinch** in a toroidal configuration. By adding a toroidal magnetic field one can get a **tokamak** and **RFP**.

t

toroidicity induced Alfvén eigenmodes Often denoted **TAE**. These are Alfvén eigenmodes that have discrete frequencies, unlike continuum or spectrum frequencies that are caused by coupling of poloidal modes. These poloidal modes combine and have gaps where these TAEs exist.

Torsatron A stellarator configuration with continuous helical coils.

torsion For the **Frenet-Serret frame**, the torsion measures the "springiness" of the trajectory. Another way of saying this, is that it measures how much the trajectory departs from simply staying in a 2D plane. The larger it is, the more the trajectory departs from a plane (and the more spread out the trajecotry spring looks like).

transmission electron microscope A type of microscope where a beam of electrons is shot through a thin layer, and the interaction between the electrons and the specimen in the thin layer are used to create an image by detecting the electrons after transmission.

transmission electron microscopy See **transmission electron microscope**. This refers to the technique rather than the instrument itself.

transport Movement of particles in a plasma. Usually this refers to macroscopic scale movement, although microscopic movement of the plasma can also be referred to.

trapped electron mode Often denoted **TEM**. This is an instability due to **trapped particles** having different behavior than **passing particles**, i.e., trapped particles act somewhat like particles trapped in a **magnetic mirror**. An electron temperature gradient can then cause an instability (also called **electron temperature gradient** instability), although number density gradients can cause this as well.

trapped ion mode Often denoted **TIM**. This is an instability due to **trapped particles** having different behavior than **passing particles**, i.e., trapped particles act somewhat like particles trapped in a **magnetic mirror**. An ion temperature gradient can cause this instability (also called **ion temperature gradient** instability).

trapped particle instabilities These are instabilities associated with **trapped particles**. There can be collisional or collisionless trapped particle instabilities, but the basic mechanism is that a gradient in some direction causes charge density ripples (polarization) that are self-reinforcing due to $\mathbf{E}\times\mathbf{B}$ drifts. See figure 21.

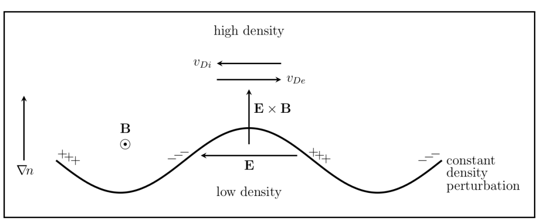

Figure 21: Trapped particle instability basic mechanism. Note that the perturbation, through $\mathbf{E}\times\mathbf{B}$ advection, reinforces the strength of the initial perturbation.

trapped particles Particles in a magnetic field that have a sufficiently large **magnetic moment** that they cannot penetrate regions of large magnetic field due to conservation of magnetic moment. In a **magnetic mirror** only trapped particles are confined, while in toroidal geometry both **passing particles** and trapped particles are confined.

triangularity This is a measure of how much the magnetic flux surface structure of the plasma is weighted toward having a triangular shape (usually at top or bottom). It is usually given by $\delta_s \equiv \frac{2(R_{\text{geo}}-R_s)}{R_{\max}-R_{\min}} = \frac{R_{\text{geo}}-R_s}{a}$ where max and min refer to the maximum R or Z value on the **LCFS**, $R_{\text{geo}} = \frac{R_{\max}+R_{\min}}{2}$ is the geometric axis, R_s refers to either $s = \text{lower}, \text{upper}$, where R_{lower} is the major radius where $Z_{\max}$ is achieved, and similarly for upper. The overall triangularity is given as $\delta = (\delta_{\text{lower}} + \delta_{\text{upper}})/2$.

tritium A rare isotope of hydrogen with 1 proton and 2 neutrons and a nearly 12-year half-life.

triton A nucleus of the rare isotope of hydrogen **tritium**. That is a particle with 1 proton and 2 neutrons.

Troyon factor See **normalized beta**.

Troyon limit A limit on the maximum β for a tokamak. Above this limit the plasma is generally unstable and susceptible to **ballooning modes**. See also **normalized beta**.

true vector See **polar vector**.

tuple A list of numbers. Sometimes referrred to as n-tuple where n is the number of elements in the list.

turbulence (1) Nonlinear evolution of unstable plasma waves, mostly **microinstabilities**, that drive turbulence. Turbulence is a flow regime characterized by chaotic and stochastic property changes. (2) (Hydrodynamics) A flow regime characterized by chaotic and stochastic property changes. Associated with **Vortex** motion where $\boldsymbol{\nabla}\times\mathbf{v} = \mathbf{0}$ where $\mathbf{v}$ is the **flow velocity**. Sometimes that restriction on the curl is relaxed, but other times this state where curl is nonzero is called **non-irrotational**. (3) Turbulence is a nonlinear dynamical behavior with randomness and irreversibility, the excitation of fluctuations over a broad range of scales, and exchanges of energy of fluctuations over the range of scales.

turbulent transport This is transport (often diffusion) that is due to turbulence in the plasma. It is sometimes referred to as **anomalous transport**, although it is no longer anomalous if it is accounted for by turbulence.

twisting mode These are waves/instabilities that form in resistive plasmas due to **reconnection** of magnetic field lines. That is, they are modes associated with changing of the magnetic field topology. They are, specifically, the odd (spatial) parity **eigenmodes**.

U u

unmagnetized plasma A plasma under no to weak effects from a magnetic field. It is the same as saying the plasma **beta** is large enough that magnetic field effects are weak.

upper hybrid frequency Is the frequency of the **upper hybrid wave**.

upper hybrid wave A type of plasma wave at the frequency of the **upper hybrid frequency**.

ut tensio, sic vis Latin. Meaning "as the extension, so the force." This was how Robert Hooke announced his discovery of **Hooke's law**.

V v

vacuum arc A device for creating a plasma from solid metal. An arc is struck on the metal which vaporizes and ionizes the metal which continues the arc.

vacuum permeability See **permeability of free space**.

vacuum permittivity See **permittivity of free space**.

Van Allen radiation belts Radiation belts in plasma regions in Earth's magnetosphere where charged particles are trapped by a **magnetic mirror** effect.

Van Leeuwen theorem See **Bohr-Van Leeuwen theorem**.

vector (1) an object with a direction and magnitude that must obey certain rotational transformation properties (see **tensor field**) (2) A **tuple** that transforms in a certain way under a change of coordinates. [Sometimes **vector** is used for both **axial vectors** and **polar vectors** despite their different transformation properties.]

vector field A quantity that assigns a vector to every point in a coordinate system.

v

vector potential For a **solenoidal field B**, there is another vector field **A** that generates **B** through $\boldsymbol{\nabla} \times \mathbf{A} = \mathbf{B}$. The vector field **A** is called the vector potential of **B**.

velocity This is the time derivative of position. Usually denoted **v**, it gives both the direction of movement, and the **speed** at which something is moving.

vertical displacement event When the entire plasma column moves outward from the **magnetic axis**. It is of major concern for fusion energy as it deposits power into the confinement vessel.

viscosity A measurement of a fluid's resistance to **shear stress** or **tensile stress**. The coefficient measuring this is often denoted as η.

viz Latin. Short for *videlicet*. This translates as "namely", "to wit", or "that is to say". This is used to indicate (near) completeness in a list and a description of what was stated before (as opposed to the more general i.e., and e.g.).

Vlasov equation The collisionless plasma **distribution function** evolution equation. It is given by $\frac{\partial f}{\partial t} + \mathbf{v} \cdot \frac{\partial f}{\partial \mathbf{x}} + \frac{q}{m} (\mathbf{E} + \mathbf{v} \times \mathbf{B}) \cdot \frac{\partial f}{\partial \mathbf{v}} = 0$ where f is the distribution function, **v** is the velocity space coordinate, **E** and **B** are the electric and magnetic fields, and q and m are electric charge and mass. It was proposed by Anatoly Vlasov in 1938.

volumetric expansion coefficient See **coefficient of thermal expansion**.

vortex A region where a fluid spins around an imaginary axis.

vortex filament A **vortex tube** with a sufficiently small cross section that **vortex strength**, $|\boldsymbol{\nabla} \times \mathbf{v}|$, is constant.

vortex lines Curves whose tangent always point in the direction of $\boldsymbol{\nabla} \times \mathbf{v}$ with **v** a **flow velocity**. Similar to **magnetic field lines**. In fact, because $\boldsymbol{\nabla} \cdot (\boldsymbol{\nabla} \times \mathbf{v}) = 0$ it is almost exactly analogous.

vortex strength For a **flow velocity**, **v**, the magnitude of the **vorticity** for the flow velocity is the vortex strength (i.e., $|\boldsymbol{\nabla} \times \mathbf{v}|$).

vortex tube A surface made up of many **vortex lines** that fill in the surface. Compare **magnetic surfaces** for the magnetic analogy.

vorticity Given a flow (or **flow velocity**), **v**, the vorticity is given by the curl of the flow and is usually denoted $\boldsymbol{\omega}$ ($\boldsymbol{\omega} = \boldsymbol{\nabla} \times \mathbf{v}$).

vorticity advection model A model of **filaments** similar to the **sheath dissipation model**, except parallel currents are neglected instead of parallel gradients.

W w

wakefield acceleration Particle acceleration due to either a laser or electron beam to drive a plasma wave in the wake of the laser/electron beam.

wavelength The wavelength is usually denoted λ, and measures the distance between two crests (or alternatively, two troughs or two points of the same "phase") on a wave.

wavenumber The wavenumber is usually denoted k and given by $k = \frac{2\pi}{\lambda}$ (rarely $1/\lambda$) where λ is the wavelength.

weakly ionized plasma A plasma where only a small fraction of the particles making up the plasma are ionized. The few ionized particles may be the dominant particle dynamics, however.

whistler wave An electron cyclotron wave. Given its name because lower frequencies travel slower than higher frequencies leading to a "whistle" sound in radios.

X x

X-divertor A **divertor** arrangement where a second **X-point** is placed downstream from the plasma X-point and in so doing spread the energy deposition over a larger area on the divertor plate.

X-pinch A device similar to the **Z-pinch**. Two wires cross in an X shape. Large currents in the wires are driven creating a **Z-pinch** which collapses and releases **x-rays**.

X-point A region wehere **electrical resistivity** is no longer negligible where the **magnetic field line** topology locally looks like an X. It can be veiwed as the region where the magnetic field line "velocity" deviates from the **fluid velocity** (breaking the **frozen flux theorem**) and becomes undefined. It is more like X-lines than a point, but it does look like an X, and is formed by a separatrix around an **O-point**.

x-rays Electromagnetic radiation of wavelength 10^{-2} to 10 nanometers (3×10^{16} to 3×10^{19} Hz or 100 eV to 100 keV).

Y y

Young's modulus The linear modulus of elasticity, that is the "**Hooke's law**" for a solid. It measures how stiff a material is. Given a displacement x and a strain P then $P = Ex$ holds and E is Young's modulus.

Z z

Z function See **plasma dispersion function**.

Z-Pinch A cylindrical device with current in the **Z** direction. This device has excellent confinement, but poor stability.

zeroth law of thermodynamics That objects in contact with each other obey the law of transitivity with respect to temperature. That is, two objects in thermal equilibrium with a system, are in thermal equilibrium with each other. For example, block $\mathcal{A}$ of tempearature T is put in contact with block $\mathcal{B}$ which becomes temperature T ($\mathcal{A}$ remaining at temperature T). If now block $\mathcal{C}$ is put in contact with block $\mathcal{A}$ but not touching block $\mathcal{B}$, and becomes temperatrue T of block $\mathcal{A}$ ($\mathcal{A}$ remaining at temperature T), then block $\mathcal{C}$ and block $\mathcal{B}$ are both at temperature T. This basically just states thermometers make sense. It is called the zeroth because it is so basic that the other thermodynamic law's names had become convention by the time this law, which is more basic, was formulated as a law.

zonal flow This a flow that shows no variation in one direction, and, in plasmas, is associated with better transport (by breaking up large eddies). For example, a zonal flow on Earth is a flow along a line of latitude (it varies as one moves North or South, but not as one moves East or West). Note that the plasma phenomenon is named after the atmospheric phenomenon. They are usually considered toroidally symmetric band-like shear flows. They are then toroidal mode number $n = 0$ modes generally. They often have small poloidal mode numbers (sometimes $m = 0$, as well).

Index