GPAP Summer School, MB summary

Here are my top ten take-home points from the GPAP school. doc

1. **Plasma** is a quasineutral assemblage of charged particles (gas or fluid), with $kT \gg e\phi_{particle}$, that exhibits collective behavior. Temperatures range from 1 eV to 10^5 eV. Densities range from $n = 1\ cm^{-3}$ in the solar wind to $n = 10^{20}\ cm^{-3}$ in a laser plasma experiment. Magnetic fields range from μG (solar wind is 100 μG or 10 nT) to MG (pulsars).

2. Prototypical collective behavior is the **plasma oscillation** with frequency $\omega_p = \sqrt{ne^2/m\epsilon_0}$. This is the fastest wiggling in a plasma.

3. A single proton will execute **cyclotron orbits** in a magnetic field at $\rho_c = Mv/qB$ and a frequency $\omega_c = qB/M$. Typically, $\omega_p \gg \omega_c$. Gradients in $|B|$ and electric fields give rise to drifts.

4. Electric potentials are shielded in plasmas with a scale called the **Debye length**: $\lambda_D = \sqrt{kT\epsilon_0/ne^2}$. This is the smallest scale in a plasma.

5. **Collisions** in plasma scale like $1/v^3$, so hot plasmas are less collisional.

6. **The plasma parameter** (number of particles in a Debye sphere) is: $\Lambda = n\lambda_D^3$, turns out $4\pi\Lambda = \omega_{pe}/\nu_{coll} \gg 1$ is a good definition of plasma.

7. **MHD equations:** $m\mathbf{a} = \mathbf{F} = \mathbf{J} \times \mathbf{B} - \nabla P$, continuity, Ohm's law $\mathbf{E} + \mathbf{u} \times \mathbf{B} = \eta\mathbf{J}$, Maxwell's equations. Curl of Ohm's law gives $\partial\mathbf{B}/\partial t = \nabla \times (u \times \mathbf{B}) + (\eta/\mu_0)\nabla^2\mathbf{B}$, called the induction equation. Ratio of the convective term to the diffusive term is the magnetic Reynolds number: $R_m = \mu_0 \ell v/\eta$. Lundquist number is $S = \mu_0 \ell v_{Alf}/\eta > R_m$.

8. **Frozen-in flux.** Plasma and magnetic field move together if plasma is hot and resistivity is low. Comes from $\mathbf{E} + \mathbf{u} \times \mathbf{B} = 0$

9. Plasmas exhibit a wide variety of **wave behavior** (Alfven, fast, slow), and **instabilities** (Rayleigh-Taylor, Kelvin-Helmholtz, kink).

10. **Interesting applications of plasmas** include (with unanswered questions): magnetic reconnection (rate $u_{in}/u_{out} = 0.1$, energy partition), turbulence (how is energy dissipated at the smallest scales in a plasma), shocks, acceleration of cosmic rays (process, power law), dynamo (how do astrophysical objects make magnetic field), astrophysical jets (how do Mpc jets stay collimated), fusion (another approach besides tokamak, lasers, mirror, z-pinch). Turbulent spectra of energy have power law behavior: $E_{K,B}(k) = C\epsilon^{2/3}k^{-5/3}$. Accelerated charged particles have a power law behavior in energy: $dN/dE \propto E^{-2.8}$.