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, sausage).

10. **Interesting applications of plasmas** include (with unanswered questions): magnetic reconnection (rate $u_{in}/u_{out} = 0.1$, energy partition, pair plasmas), turbulence (how is energy dissipated at the smallest scales in a plasma), shocks (magnetized, collisionless), 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: $dN/dE \propto E^{-2.8}$.