

## **APh 156A: Organization and Policies**

- **Instructor:** Paul M. Bellan, 126 Watson, x 4827, MS 128-95, email pbellan@its.caltech.edu  
**Teaching Assistant:** Deepak Kumar, 130 Watson, deeku@caltech.edu

**Class list:** Please fill out the class list and also fill out your timetable.

**Grading policy:** Homework 40%, exams 60% (see copy of previous year grading scheme for reference)

**Collaboration policy:** see attached form

**Text:** “*Fundamentals of Plasma Physics*” by P. M. Bellan

**Syllabus:** The class will be all year (fall, winter, spring quarters) and slightly less than one third of the text will be covered each term so that most, but not all of the text will be covered. The table of contents of the text is given on the following pages. Homework will be assigned as appropriate to the material that has been covered so that the homework load will be variable but significant. A small portion of the homework will involve simple numerical calculations and assistance will be provided for any students unfamiliar with these methods.

**Additional Reference books (on reserve in library):**

1. Schmidt, *The Physics of High Temperature Plasmas*
2. Krall and Trivelpiece, *Plasma Physics*
3. Nicholson, *Introduction to Plasma Theory*
4. Chen, *Introduction to Plasma Physics*

### **Prerequisites:**

It is assumed that students have some familiarity with electricity and magnetism, Maxwell’s equations, ordinary and partial differential equations, complex analysis, linear algebra, classical mechanics. However, these concepts will be briefly reviewed each time they are first used and students unfamiliar with some of these concepts will be assisted as appropriate.

## Contents

<i>Preface</i>	<i>page</i> xiii
<b>1 Basic concepts</b>	<b>1</b>
1.1 History of the term “plasma”	1
1.2 Brief history of plasma physics	1
1.3 Plasma parameters	3
1.4 Examples of plasmas	4
1.5 Logical framework of plasma physics	4
1.6 Debye shielding	7
1.7 Quasi-neutrality	11
1.8 Small- vs. large-angle collisions in plasmas	12
1.9 Electron and ion collision frequencies	16
1.10 Collisions with neutrals	19
1.11 Simple transport phenomena	20
1.12 A quantitative perspective	23
1.13 Assignments	25
<b>2 The Vlasov, two-fluid, and MHD models of plasma dynamics</b>	<b>34</b>
2.1 Overview	34
2.2 Phase-space	34
2.3 Distribution function and Vlasov equation	35
2.4 Moments of the distribution function	38
2.5 Two-fluid equations	41
2.6 Magnetohydrodynamic equations	52
2.7 Summary of MHD equations	61
2.8 Classical transport	62
2.9 Sheath physics and Langmuir probe theory	64
2.10 Assignments	69

viii	<i>Contents</i>	
<b>3</b>	<b>Motion of a single plasma particle</b>	<b>75</b>
3.1	Motivation	75
3.2	Hamilton–Lagrange formalism vs. Lorentz equation	76
3.3	Adiabatic invariant of a pendulum	80
3.4	Extension of WKB method to general adiabatic invariant	83
3.5	Drift equations	88
3.6	Relation of drift equations to the double adiabatic MHD equations	108
3.7	Non-adiabatic motion in symmetric geometry	115
3.8	Particle motion in small-amplitude oscillatory fields	129
3.9	Wave–particle energy transfer	131
3.10	Assignments	142
<b>4</b>	<b>Elementary plasma waves</b>	<b>146</b>
4.1	General method for analyzing small-amplitude waves	146
4.2	Two-fluid theory of unmagnetized plasma waves	147
4.3	Low-frequency magnetized plasma: Alfvén waves	155
4.4	Two-fluid model of Alfvén modes	164
4.5	Assignments	172
<b>5</b>	<b>Streaming instabilities and the Landau problem</b>	<b>174</b>
5.1	Overview	174
5.2	Streaming instabilities	174
5.3	The Landau problem	180
5.4	The Penrose criterion	200
5.5	Assignments	203
<b>6</b>	<b>Cold plasma waves in a magnetized plasma</b>	<b>206</b>
6.1	Overview	206
6.2	Redundancy of Poisson’s equation in electromagnetic mode analysis	206
6.3	Dielectric tensor	208
6.4	Dispersion relation expressed as a relation between $n_x^2$ and $n_z^2$	223
6.5	A journey through parameter space	225
6.6	High-frequency waves: Altar–Appleton–Hartree dispersion relation	228
6.7	Group velocity	233
6.8	Quasi-electrostatic cold plasma waves	234
6.9	Resonance cones	236
6.10	Assignments	240

<b>7</b>	<b>Waves in inhomogeneous plasmas and wave-energy relations</b>	<b>242</b>
7.1	Wave propagation in inhomogeneous plasmas	242
7.2	Geometric optics	245
7.3	Surface waves – the plasma-filled waveguide	247
7.4	Plasma wave-energy equation	253
7.5	Cold plasma wave-energy equation	255
7.6	Finite-temperature plasma wave-energy equation	259
7.7	Negative energy waves	260
7.8	Assignments	263
<b>8</b>	<b>Vlasov theory of warm electrostatic waves in a magnetized plasma</b>	<b>265</b>
8.1	Solving the Vlasov equation by tracking each particle's history	265
8.2	Analysis of the warm plasma electrostatic dispersion relation	272
8.3	Bernstein waves	273
8.4	Finite $k_{\parallel}$ dispersion: linear mode conversion	276
8.5	Analysis of linear mode conversion	279
8.6	Drift waves	289
8.7	Assignments	304
<b>9</b>	<b>MHD equilibria</b>	<b>305</b>
9.1	Why use MHD?	305
9.2	Vacuum magnetic fields	306
9.3	Force-free fields	309
9.4	Magnetic pressure and tension	310
9.5	Magnetic stress tensor	312
9.6	Flux preservation, energy minimization, and inductance	314
9.7	Static versus dynamic equilibria	316
9.8	Static equilibria	316
9.9	Dynamic equilibria: flows	328
9.10	Assignments	338
<b>10</b>	<b>Stability of static MHD equilibria</b>	<b>342</b>
10.1	Introduction	342
10.2	The Rayleigh–Taylor instability of hydrodynamics	343
10.3	MHD Rayleigh–Taylor instability	346
10.4	The MHD energy principle	351
10.5	Discussion of the energy principle	365
10.6	Current-driven instabilities and helicity	366
10.7	Magnetic helicity	367
10.8	Characterization of free-boundary instabilities	370

x	<i>Contents</i>	
	10.9 Analysis of free-boundary instabilities	374
	10.10 Assignments	383
<b>11</b>	<b>Magnetic helicity interpreted and Woltjer–Taylor relaxation</b>	<b>385</b>
	11.1 Introduction	385
	11.2 Topological interpretation of magnetic helicity	385
	11.3 Woltjer–Taylor relaxation	392
	11.4 Kinking and magnetic helicity	394
	11.5 Assignments	407
<b>12</b>	<b>Magnetic reconnection</b>	<b>410</b>
	12.1 Introduction	410
	12.2 Water-beading: an analogy to magnetic reconnection	412
	12.3 Qualitative description of sheet current instability	413
	12.4 Semi-quantitative estimate of the tearing process	416
	12.5 Generalization of tearing to sheared magnetic fields	424
	12.6 Magnetic islands	430
	12.7 Assignments	432
<b>13</b>	<b>Fokker–Planck theory of collisions</b>	<b>436</b>
	13.1 Introduction	436
	13.2 Statistical argument for the development of the Fokker–Planck equation	438
	13.3 Electrical resistivity	450
	13.4 Runaway electric field	451
	13.5 Assignments	453
<b>14</b>	<b>Wave–particle nonlinearities</b>	<b>456</b>
	14.1 Introduction	456
	14.2 Vlasov nonlinearity and quasi-linear velocity space diffusion	458
	14.3 Echoes	473
	14.4 Assignments	489
<b>15</b>	<b>Wave–wave nonlinearities</b>	<b>491</b>
	15.1 Introduction	491
	15.2 Manley–Rowe relations	493
	15.3 Application to waves	499
	15.4 Instability onset via nonlinear dispersion method	511
	15.5 Digging a density hole via ponderomotive force	517
	15.6 Ion acoustic wave soliton	523
	15.7 Assignments	527

<i>Contents</i>		xi
<b>16 Non-neutral plasmas</b>		<b>530</b>
16.1	Introduction	530
16.2	Brillouin flow	530
16.3	Isomorphism to incompressible 2-D hydrodynamics	533
16.4	Near-perfect confinement	535
16.5	Diocotron modes	537
16.6	Assignments	550
<b>17 Dusty plasmas</b>		<b>556</b>
17.1	Introduction	556
17.2	Electron and ion current flow to a dust grain	557
17.3	Dust charge	559
17.4	Dusty plasma parameter space	563
17.5	Large $P$ limit: dust acoustic waves	564
17.6	Dust ion acoustic waves	568
17.7	The strongly coupled regime: crystallization of a dusty plasma	569
17.8	Assignments	579
<b>Appendices</b>		
A	Intuitive method for vector calculus identities	582
B	Vector calculus in orthogonal curvilinear coordinates	586
C	Frequently used physical constants and formulae	593
	<i>Bibliography and suggested reading</i>	597
	<i>References</i>	599
	<i>Index</i>	604

APh 156

grading example from previous year (actual problem numbers and selected problems may be different this year)

MAXIMUM

<b>SET 1</b>	
CHAP1-1	10
CHAP1-2	5
CHAP1-3	10
<b>SET 1 TOTAL</b>	<b>25</b>
<b>SET 2</b>	
CHAP1-5	5
CHAP1-6	10
CHAP1-7	10
CHAP1-8	10
CHAP1-9	10
<b>SET 2 TOTAL</b>	<b>45</b>
<b>SET 3</b>	
CHAP2-4	5
CHAP2-5	5
CHAP2-8	10
CHAP2-9	10
<b>SET 3 TOTAL</b>	<b>30</b>
<b>SET 4</b>	
CHAP3-1	10
CHAP3-2	10
CHAP3-3	10
CHAP3-4	10
CHAP3-5	10
<b>SET 4TOTAL</b>	<b>50</b>
<b>SET 5</b>	
CHAP3-6	10
CHAP3-7	10
CHAP3-9	10
CHAP3-11	10
CHAP3-13	10
<b>SET 5 TOTAL</b>	<b>50</b>
<b>TOTAL</b>	<b>200</b>
<b>% OF TOTAL</b>	<b>1</b>

## Final

Part A-closed book

(do 3 of 5 questions)

question 1	30
question 2	30
question 3	30
question 4	30
question 5	30

**Total part A** 90

Part B- open book

question 1	30
question 2	30
question 3	40
<b>Total part B</b>	<b>100</b>

**total exam A&B** 190

**exam out of 100% (A&B)** 100

40% of HW 40

60% of exam 60

**Total HW+exam** 100

**grade**

September 21, 2007

Name \_\_\_\_\_  
Year (Junior, Senior, 1st yr grad, etc.) \_\_\_\_\_  
Option (Aph, Physics, etc.) \_\_\_\_\_  
Registered in class? \_\_\_\_\_  
Address \_\_\_\_\_  
Phone \_\_\_\_\_  
E-Mail \_\_\_\_\_

Schedule  
(list classes and obligations)

	<b>Mon</b>	<b>Tue</b>	<b>Wed</b>	<b>Thu</b>	<b>Fri</b>
8:00					
8:30					
9:00					
9:30					
10:00					
10:30					
11:00					
11:30					
12:00					
12:30					
1:00					
1:30					
2:00					
2:30					
3:00					
3:30					
4:00					