

Contents

Preface	xi
Symbols and Constants	xiii
1 Small-Amplitude Waves in a Plasma	
1. Introduction	1
2. The wave equation	1
3. Waves in a cold plasma with no static magnetic field	4
4. The general dispersion equation for a collisionless plasma	7
5. Waves in a cold plasma in a magnetic field	10
5.1 $k_{\perp} = 0$	11
5.2 $k_{\parallel} = 0$	15
5.3 Propagation of transverse waves in overdense plasmas	17
6. Growth and decay of waves	18
7. Longitudinal waves in hot plasmas with no static magnetic field	19
8. Waves in a hot magnetized plasma	23
2 Radiative Energy Transfer	
1. Introduction	24
2. Some definitions	24
3. Emission processes in a plasma	26
3.1 Bound-bound transitions	26
3.2 Free-bound transitions	27
3.3 Free-free transitions	27
3.4 Cyclotron radiation	28
3.5 Čerenkov radiation	28
4. Black body radiation	29

5.	The Einstein relations	30
6.	Radiation from a finite plasma	34
7.	Plasma models	36
	7.1 Local thermal equilibrium (LTE)	36
	7.2 Coronal equilibrium	37
	7.3 Collisional-radiative equilibrium	38
	7.4 Transient effects	39
8.	Bremsstrahlung emission and absorption	39
	8.1 Binary processes	39
	8.1.1 <i>Electron-ion Bremsstrahlung emission from Maxwellian plasmas</i>	40
	8.1.2 <i>Electron-ion Bremsstrahlung absorption from weak radiation fields</i>	44
	8.1.3 <i>Electron-ion Bremsstrahlung processes in strong radiation fields</i>	46
	8.1.4 <i>Electron-atom Bremsstrahlung processes</i>	47
	8.1.5 <i>Ion-ion collisions in strong radiation fields</i>	49
	8.2 Collective effects	49
	8.3 Relativistic effects: electron-electron Bremsstrahlung	50
	8.4 Bremsstrahlung emission from a finite plasma	52
	8.5 Experimental measurements of Bremsstrahlung coefficients	52
	8.5.1 <i>Fully-ionized plasmas</i>	52
	8.5.2 <i>Partially-ionized gases</i>	53
9.	Parametric interactions	54
	9.1 Basic theory	55
	9.2 Parametric instabilities	59
	9.2.1 <i>Onset of instability</i>	59
	9.2.2 <i>Development of the instability</i>	64
	9.3 'Two-plasmon' instability	69
	9.4 Coupling of two laser beams to a plasma wave	70
	9.5 Stimulated Raman and Brillouin scattering	70
10.	Other non-linear interactions	73
	10.1 Stimulated Compton scattering	73
	10.2 Optical resonance absorption	74
	10.3 Relativistic effects	75
11.	Experimental studies of non-linear interactions of radiation with plasmas	75
	11.1 Microwave experiments	75
	11.2 Laser experiments	77

3 Incoherent Scattering of Light by Plasmas

1.	Introduction	82
2.	Scattering by a single free particle	83

3.	Effect of motion of a single scattering particle on the wavelength of scattered light	85
4.	Effects of density fluctuations	86
5.	Some calculations of scattered light spectra	88
5.1	Maxwellian velocity distributions	88
5.2	The Salpeter approximation	90
5.3	The ion-acoustic wave resonance	93
5.4	Effects of a drift velocity of electrons relative to ions	95
5.5	Effects of a magnetic field	96
5.6	Effects of collisions	98
5.7	Effects of impurities	100
5.8	Effects of inhomogeneities in the plasma	102
5.9	Effects of large-amplitude fluctuations	102
5.10	Effects of high temperatures	102
6.	Power and energy requirements for the incident beam: the problem of self-luminosity	104
7.	Experimental methods	108
7.1	The light source	108
7.2	Methods of reducing stray light	109
7.3	Methods of analysing and detecting the scattered light	110
7.4	Calibration of the scattering system	112
8.	Experimental observations of scattered light from plasmas	112
8.1	Experiments in which $\alpha < 1$	113
8.2	Experiments in which $\alpha \gtrsim 1$	117
8.3	Studies of magnetic field effects	128
4	Thermonuclear Reactions	
1.	Introduction	132
2.	Nuclear reaction rates	132
3.	Initiation of reactions:	135
4.	Containment	139
4.1	Magnetic containment	139
4.2	Inertial containment	140
5.	Triggered reactions	141
6.	Fission reactions	143
7.	Design studies for fusion reactors	143
5	Ionization and Breakdown of Gases by Light	
1.	Introduction	145
2.	Multi-photon ionization theory	146
3.	Experimental studies of initiation of breakdown	154
4.	Development of ionization leading to breakdown	163
4.1	Cascade theory of breakdown	163
4.2	Calculations of gas breakdown thresholds	167

5.	Measurements of breakdown thresholds	170
5.1	Observations with <i>Q</i> -switched ruby and neodymium lasers (10^{-8} to 10^{-7} s)	172
5.1.1	<i>Dependence of breakdown threshold on gas density and dimensions of focal volume</i>	172
5.1.2	<i>Frequency dependence of breakdown threshold</i>	181
5.2	Observations with mode-locked ruby and neodymium lasers (10^{-12} to 10^{-10} s)	185
5.3	Observations with carbon dioxide lasers	188
5.4	Effects of magnetic fields on breakdown thresholds	193
6.	Self-focusing of laser beams in gases	195

6 Plasmas Formed by Light in Gases

1.	Introduction	200
2.	Breakdown wave theory	201
3.	Detonation wave theory	203
3.1	Effects of ionization	211
4.	Plasma-radiation-propagated wave theory	215
4.1	Optically thick plasma	216
4.2	Optically thin plasma	218
5.	Behaviour of plasma after laser pulse has ceased	220
6.	Computer calculations	220
7.	Heating of magnetically-confined plasmas by laser beams	222
8.	Diagnostic techniques for plasmas formed in gases	222
8.1	High-speed photography	223
8.2	Shadow and schlieren photography	223
8.3	Interferometric and holographic studies	227
8.4	Spectroscopic observations of light emitted by plasma	230
8.5	X-ray intensity measurements	231
8.6	Microwave measurements	232
8.7	Optical transmission measurements	234
9.	Studies of plasmas formed by ruby and neodymium laser pulses	234
9.1	Pulses of duration greater than 10^{-9} s	234
9.1.1	<i>Laser power up to ~ 10 MW</i>	234
9.1.2	<i>Laser power between ~ 10 and ~ 100 MW</i>	248
9.1.3	<i>Laser power between ~ 100 MW and ~ 1 GW</i>	256
9.1.4	<i>Laser power above 1 GW</i>	261
9.2	Mode-locked pulses	263
10.	Plasmas heated by carbon dioxide lasers	265
10.1	Plasmas formed by pulsed lasers in cold gases	265
10.2	Heating of existing plasmas by laser radiation	269
10.3	Plasmas sustained by c.w. lasers	269
11.	Magnetic effects	271

7 Theory of Plasmas Formed by Light Incident on Solids

1. Introduction	273
2. Initial stages of plasma formation from solid targets in vacuum	274
2.1 Thermal conductivity calculations	274
2.2 Effects of melting and vaporization	276
2.3 Thermal ionization	277
2.4 Multi-photon ionization of solids	279
3. Reflectivity of a plasma boundary	280
4. Plasmas formed from semi-infinite solid targets	285
4.1 Self-regulating plasma evolved from shock-compressed surface layer	287
4.2 Deflagration preceded by a shock wave	293
4.3 Thermal wave followed by a rarefaction wave	300
4.4 The limit of thermal conductivity	306
5. Plasmas formed from thin solid films	307
6. Spherical plasmas with uniform temperature	310
6.1 Heating limits in underdense plasma	316
6.2 Decay of uniform-temperature plasma	317
7. Shock waves in spherical plasmas	319
8. Isentropic compression	321
8.1 Degeneracy	323
8.2 Computer calculations of spherical implosions	324
8.3 Symmetry and stability	326
8.4 Effects of fast electrons	329
9. Magnetic effects	331
9.1 Plasma in an externally applied field	331
9.2 Spontaneous magnetic fields	336
9.3 Laser-compressed magnetic fields	337

8 Experimental Studies of Plasmas Formed by Light Incident on Solids

1. Introduction	338
2. Plasmas formed from massive targets in vacuum	339
2.1 Millisecond laser pulses	339
2.2 Nanosecond laser pulses	340
2.2.1 <i>Laser power up to 100 MW</i>	340
2.2.2 <i>Laser power from 100 MW to 1 GW</i>	363
2.2.3 <i>Laser power above 1 GW</i>	387
2.3 Picosecond laser pulses	391
3. Plasmas formed from thin solid films	395
4. Plasmas formed from small isolated targets	399
4.1 Methods of suspension	400
4.2 Experiments using single laser beams	403
4.3 Experiments using multiple laser beams	408

5. Plasmas formed from solid hydrogen isotope targets	412
5.1 Methods of target preparation	412
5.2 Plasmas formed from filaments	417
5.3 Plasmas formed from thin solid films	426
5.4 Plasmas formed from isolated pellets	428
6. Effects of magnetic fields on plasmas formed from solid targets in vacuum	429
6.1 Low magnetic fields ($B < 10^5$ G)	429
6.2 High magnetic fields ($B \geq 10^5$ G)	434
7. Plasmas formed from solid targets in gases	435
7.1 Plasmas formed by ruby and neodymium lasers	435
7.2 Plasmas formed by carbon dioxide lasers	441
Appendix A	445
Appendix B	447
References	449
Index	503