

SOCIETÀ ITALIANA DI FISICA

RENDICONTI  
DELLA  
SCUOLA INTERNAZIONALE DI FISICA  
« ENRICO FERMI »

XLVIII CORSO

*Fisica delle alte densità di energia*



ACADEMIC PRESS • NEW YORK AND LONDON

252  
KY

7962820

SOCIETA' ITALIANA DI FISICA

RENDICONTI  
DELLA  
SCUOLA INTERNAZIONALE DI FISICA  
«ENRICO FERMI»

XLVIII CORSO

a cura di P. CALDIROLA  
Direttore del Corso  
e di H. KNOEPFEL

VARENNA SUL LAGO DI COMO  
VILLA MONASTERO  
14-26 LUGLIO 1969

*Fisica delle alte densità di energia*

1971



ACADEMIC PRESS • NEW YORK AND LONDON

ACADEMIC PRESS INC.  
111 FIFTH AVENUE  
NEW YORK 3, N. Y.

*United Kingdom Edition*

Published by  
ACADEMIC PRESS INC. (LONDON) LTD.  
BERKELEY SQUARE HOUSE, LONDON W. 1

COPYRIGHT © 1971, BY SOCIETÀ ITALIANA DI FISICA

ALL RIGHTS RESERVED

NO PART OF THIS BOOK MAY BE REPRODUCED IN ANY FORM,  
BY PHOTOSTAT, MICROFILM, OR ANY OTHER MEANS,  
WITHOUT WRITTEN PERMISSION FROM THE PUBLISHERS.

*Library of Congress Catalog Card Number: 72-119469*

PRINTED IN ITALY

1285007  
ITALIAN PHYSICAL SOCIETY

PROCEEDINGS  
OF THE  
INTERNATIONAL SCHOOL OF PHYSICS  
« ENRICO FERMI »

COURSE XLVIII

edited by P. CALDIROLA  
Director of the Course  
and by H. KNOEPFEL

VARENNA ON LAKE COMO  
VILLA MONASTERO  
14th - 26th - JULY 1969

*Physics of High Energy Density*

1971



ACADEMIC PRESS • NEW YORK AND LONDON

## Introduction.

P. CALDIROLA

*Istituto di Scienze Fisiche dell'Università - Milano*

Ladies and Gentlemen,

the 3rd course of this year of the International Summer School organized in Varenna by the « Società Italiana di Fisica » has as its subject the Physics of high energy density.

Before saying a few introductory words about the content of the Course that I have been charged to organize, I have the pleasure of giving to all the participants the welcome of the President of the « Società Italiana di Fisica », Prof. Giuliano Toraldo di Francia.

On account of his heavy duties, Prof. TORALDO DI FRANCIA, is not here to say the few, traditional opening words.

At the same time I would like to express my deep gratitude to him and to the Società Italiana di Fisica for having accepted a course on the Physics of High Energy Density in the program of the Varenna Summer School.

I really think that this enterprise will be extremely useful, especially for our young students, because I know that there are no high-level Courses on this topic among the European Universities.

During the last two decades the Physics of Plasmas, or, in other words, the physics of fully ionized gases, has grown in a spectacular way. This growth is mainly due to the fact that people have become aware of the possibility of obtaining a controlled release of energy from the so-called nuclear fusion reactions, as, for instance, the hydrogen-helium transformation.

To this aim it is necessary to heat the material to a temperature of the order of several hundreds of millions of degrees. Obviously, one must concentrate an extremely high energy quantity in a relatively small portion of the material.

This Course is precisely intended to face the two basic problems relevant to the afore-mentioned process. The first is how one can practically obtain such concentrations of energy, and the second is how the material will react to such enormous energy densities.

The interest in this field of the modern physical research is also due to the fact that, in this way, in the laboratory we can be faced with physical situations in which matter acquires unusual and fascinating properties.

The same properties are also verified in cosmic spaces and this is the reason why plasma physics has attracted the interest of astrophysicists.

The thorough analysis of these properties will certainly be extremely useful for an understanding of the fundamental behaviour of matter and for the technical applications, which will surely come out of our enlarged knowledge. The program of the Course has been prepared by Dr. Knoepfel who, through his well-known personal competence in this field of physical research, has made a skilfull choice of all the relevant topics. The arguments chosen, though apparently diverse, are in reality strictly closely linked with the main subject of the Course, as will be evident at the end of the various groups of lectures.

A first set of lectures will be dedicated, as we have already said, to the study of the concentration of high quantities of energy in small portions of the material.

This topic will be treated in two series of lectures: in the first by Prof. R. E. KIDDER of the Lawrence Laboratory California University, and in the second one by Prof. O. N. KROKHIN of the Lebedev Institute of Moscow.

Both these lecturers will talk about the use of gigantic light pulses produced, during extremely short time intervals, by high-power lasers. The energy is focused upon solid materials in order to achieve conditions suitable to the triggering of thermonuclear reactions.

Prof. KIDDER will describe the properties of intense laser beams emphasizing their capability to concentrate energy in small portions of the material.

As a consequence the temperature and pressure will reach extremely high levels.

Prof. Krokhin's lectures will be devoted to the detailed study of all those physical transformations taking place in the material under the action of the high-energy laser radiation, and will thus complete, in a useful way, the first set of lectures.

All the other lessons will be likewise dedicated to a thorough and systematic analysis of the behaviour of matter when it is subjected to a strong energy concentration.

The most spectacular phenomenon is given by the rapid expansion of matter which, in turns, gives rise to an intense shock wave propagating in the material. Such a strong shock wave will be accompanied by release of heat and emission of electromagnetic radiation.

To all these problems will be devoted the lectures given by Prof. G. E. DUVALL, Washington State University, Prof. R. A. GROSS, Columbia University of New York, Prof. F. D. BENNETT, Maryland University and by Prof. R. N. KEELER and Prof. E. B. ROYCE both from California University.

Prof. KEELER will give a set of preliminary lectures about the state-equation

of condensed media (particularly of solids) under conditions of extremely high pressure and temperature, with emphasis on the physical properties associated to the electron distribution in the material medium.

Prof. BENNETT will add a set of lectures dealing with vaporization waves and with phase transitions.

Prof. DUVALL will teach about shock-waves theory in dense media. He will also develop an extensive and detailed treatment of the dynamics and structure of a shock-wave propagating in a solid.

Particular attention will be given to the mechanical effects of shock-waves, which are relevant to some interesting technological applications.

Then Prof. GROSS will give a set of lectures with the principal aim of describing the ionization effects which take place in the shock-wave.

Furthermore, he will present an analysis of the shock-wave structure, when one has to take into account the radiation of electromagnetic waves and when relativistic effects modify the mathematical treatment of the process.

Prof. ROYCE will deal with a particular problem, describing the properties of a magnetic material under the strong compressions induced by the passage of a shock-wave, and finally Prof. SCHALL will illustrate some relevant topics in the detonation theory.

Two particular problems will also be treated by one of the most famous physicist of our time, Prof. E. TELLER of the California University. Prof. TELLER will present the problem of the shock-waves formation in stars and develop a model, based on the Thomas-Fermi statistical theory of the atom, which describes the electronic properties of a strongly compressed solid.

As usual, the Course will be completed by a series of Seminars on various topics of the physics of the high-energy density.

I have on my list the names of Dr. LINHART, Dr. KNOEPFEL, Dr. SOMON and Dr. CARUSO of the «Laboratori Gas Ionizzati di Frascati» and of Prof. WINTERBERG of Las Vegas University. They will speak about some special topics of great interest in our programme.

We plan also to have sufficient time available for free discussions. I hope that the formal and informal lecture and discussion meetings at this enchanting Villa Monastero will be useful and pleasant for all of you.

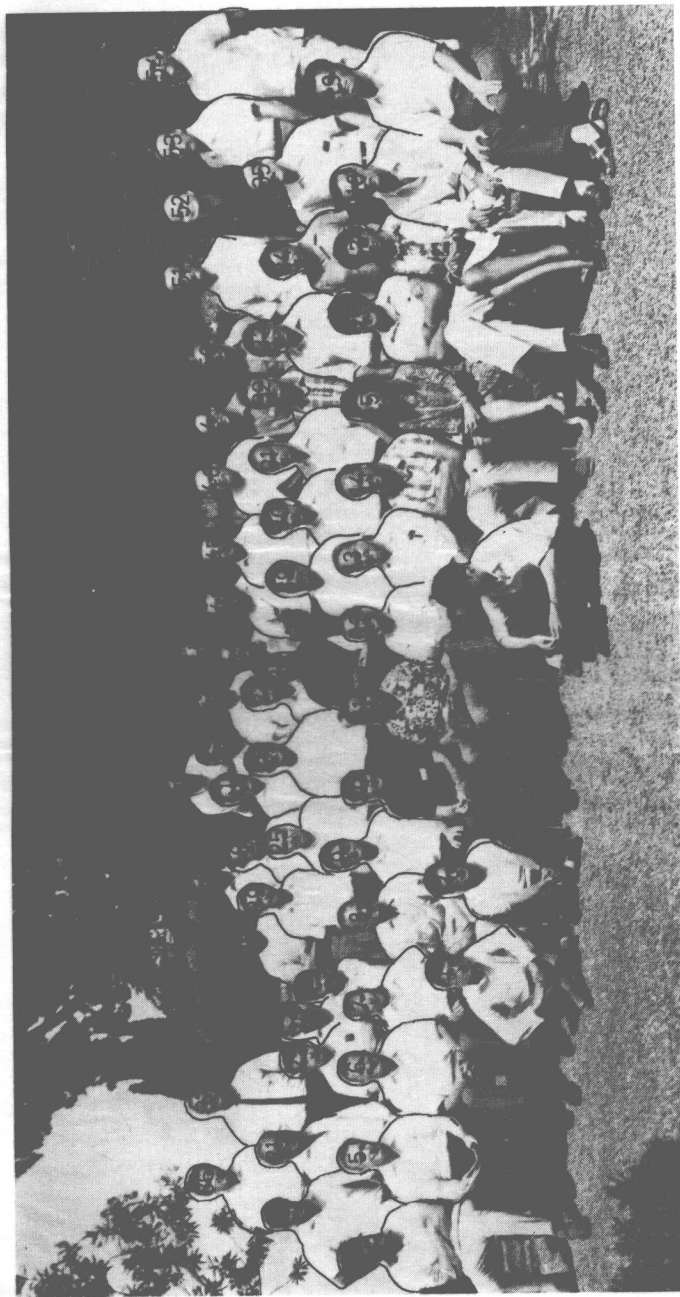
I cannot conclude this brief presentation, without saying that the major merit for arranging the whole Course goes to Dr. KNOEPFEL, who, with his authority, experience and unwielding work, has succeeded in gathering here such a number of distinguished lecturers. I am sure that all the guests of the Società Italiana di Fisica will join in thanking him for his precious and valuable collaboration.

I close my talk with the traditional expression: I open, here, this 3rd Course 1969, the 48th since the beginning of the School, and I hope it will be pleasant and successful.

SOCIETÀ ITALIANA DI FISICA

SCUOLA INTERNAZIONALE DI FISICA « E. FERMI »

XLVIII CORSO - VARENNA SUL LAGO DI COMO - VILLA MONASTERO - 14-26 Luglio 1969



1. K. Hornung  
2. M. Gambarelli  
3. J. Mrkwiczka  
4. N. Gylden  
5. G. Iernetti  
6. F. D. Bennett  
7. E. B. Royce  
8. P. Caldirola  
9. R. N. Keeler  
10. O. N. Krokhin  
11. E. Teller

12. R. A. Gross  
13. R. E. Kidder  
14. H. Knoepfel  
15. M. Pilo  
16. A. Caruso  
17. L. Saitta  
18. G. Poletti  
19. A. Gervat  
20. J. Braun  
21. J. G. Linhart  
22. C. Rioux

23. C. Maisonnier  
24. F. Grossetête  
25. R. B. Oswald  
26. R. H. Huddleston  
27. C. Summa  
28. N. Cerullo  
29. A. Di Giorgio  
30. A. Fisher  
31. J. Leorat  
32. P. Lagus  
33. G. Besançon

34. M. Samuelli  
35. R. Luppi  
36. A. Jaworowski  
37. A. Lowrey  
38. F. Grattan  
39. R. Fortin  
40. D. Schallhorn  
41. W. Wölfl  
42. E. Sindoni  
43. R. Pozzoli  
44. A. Brahmé

45. C. Fauquignon  
46. C. Chiosi  
47. A. Saggion  
48. G. Frigero  
49. Y. Avni  
50. L. Egardt  
51. L. Brun  
52. P. Berling  
53. B. Brunelli  
54. R. Grattan  
55. J. P. Sonnon  
56. C. Di Gregorio



PROCEEDINGS OF THE INTERNATIONAL SCHOOL OF PHYSICS  
« ENRICO FERMI »

- Course XIV  
*Ergodic Theories*  
edited by P. CALDIROLA
- Course XV  
*Nuclear Spectroscopy*  
edited by G. RACAI
- Course XVI  
*Physicomathematical Aspects of Biology*  
edited by N. RASHEVSKY
- Course XVII  
*Topics of Radiofrequency Spectroscopy*  
edited by A. GOZZINI
- Course XVIII  
*Physics of Solids (Radiation Damage in Solids)*  
edited by D. S. BILLINGTON
- Course XIX  
*Cosmic Rays, Solar Particles and Space Research*  
edited by B. PETERS
- Course XX  
*Evidence for Gravitational Theories*  
edited by C. MØLLER
- Course XXI  
*Liquid Helium*  
edited by G. CARERI
- Course XXII  
*Semiconductors*  
edited by R. A. SMITH
- Course XXIII  
*Nuclear Physics*  
edited by V. F. WEISSKOPF
- Course XXIV  
*Space Exploration and the Solar System*  
edited by B. ROSSI
- Course XXV  
*Advanced Plasma Theory*  
edited by M. N. ROSENBLUTH
- Course XXVI  
*Selected Topics on Elementary Particle Physics*  
edited by M. CONVERSI
- Course XXVII  
*Dispersion and Absorption of Sound by Molecular Processes*  
edited by D. SETTE
- Course XXVIII  
*Star Evolution*  
edited by L. GRATTON
- Course XXIX  
*Dispersion Relations and Their Connection with Causality*  
edited by E. P. WIGNER
- Course XXX  
*Radiation Dosimetry*  
edited by F. W. SPIERS and G. W. REED
- Course XXXI  
*Quantum Electronics and Coherent Light*  
edited by C. H. TOWNES and P. A. MILES
- Course XXXII  
*Weak Interactions and High-Energy Neutrino Physics*  
edited by T. D. LEE
- Course XXXIII  
*Strong Interactions*  
edited by L. W. ALVAREZ
- Course XXXIV  
*The Optical Properties of Solids*  
edited by J. TAUC

*Information about Courses I-XIII may be obtained from the Italian Physical Society.*

- Course XXXV  
**High-Energy Astrophysics**  
edited by L. GRATTON
- Course XXXVI  
**Many-Body Description of Nuclear Structure and Reactions**  
edited by C. BLOCH
- Course XXXVII  
**Theory of Magnetism in Transition Metals**  
edited by W. MARSHALL
- Course XXXVIII  
**Interaction of High-Energy Particles with Nuclei**  
edited by T. E. O. ERICSON
- Course XXXIX  
**Plasma Astrophysics**  
edited by P. A. STURROCK
- Course XL  
**Nuclear Structure and Nuclear Reactions**  
edited by M. JEAN
- Course XLI  
**Selected Topics in Particle Physics**  
edited by J. STEINBERGER
- Course XLII  
**Quantum Optics**  
edited by R. J. GLAUBER
- Course XLIII  
**Processing of Optical Data by Organisms and by Machines**  
edited by W. REICHARDT
- Course XLIV  
**Molecular Beams and Reaction Kinetics**  
edited by CH. SCHLIER
- Course XLV  
**Local Quantum Theory**  
edited by R. JOST
- Course XLVI  
**Physics with Storage Rings**  
edited by B. TOUSCHEK
- Course XLVII  
**General Relativity and Cosmology**  
edited by R. K. SACHS

## INDICE

P. CALDIROLA - Introduction. . . . . pag. XII

Gruppo fotografico dei partecipanti al Corso . . . . . fuori testo

E. TELLER - Some thoughts about high energy densities. . . pag. 1

G. E. DUVAL - Shock waves in condensed media.

|   |   |    |
|---|---|----|
| 1. Basic shock relations . . . . .                                  | » | 7  |
| 2. Rarefactions and characteristics . . . . .                       | » | 11 |
| 3. Elementary wave interactions . . . . .                           | » | 15 |
| 4. Elastic-plastic solids. . . . .                                  | » | 23 |
| 5. Solid-solid phase transitions . . . . .                          | » | 28 |
| 6. Stress-relaxation in elastic-plastic solids . . . . .            | » | 32 |
| 7. Irreversible phase transitions. . . . .                          | » | 38 |
| 8. Mechanical effects. . . . .                                      | » | 42 |
| 9. Shock waves on a one-dimensional lattice of mass points. . . . . | » | 47 |

R. N. KEELER and E. B. ROYCE - Shock waves in condensed media.

|   |   |    |
|---|---|----|
| I. - Experimental techniques. R. N. KEELER. . . . .   | » | 51 |
| 1'1. Background . . . . .   | » | 51 |
| 1'2. Experimental equipment . . . . .   | » | 57 |
| 1'2.1. Plane-wave lenses . . . . .  | » | 57 |
| 1'2.2. Gas and powder guns . . . . .  | » | 58 |
| 1'2.3. Streaking camera . . . . .   | » | 59 |
| 1'2.4. Argon candle . . . . .   | » | 59 |
| 1'2.5. The argon flash gap . . . . .  | » | 60 |
| 1'3. Discrete techniques. . . . .   | » | 60 |
| 1'3.1. Pin techniques. . . . .  | » | 61 |
| 1'3.2. Streaking camera equation-of-state experiments<br>using flash gap techniques . . . . . | » | 63 |

|   |  |      |     |
|---|--|------|-----|
| 1'4.  | Continuous method . . . . .  | pag. | 65  |
| 1'4.1.  | Capacitor technique . . . . .  | »    | 65  |
| 1'4.2.  | The inclined-prism technique . . . . .   | »    | 67  |
| 1'5.  | Internal techniques . . . . .  | »    | 69  |
| 1'5.1.  | The electromagnetic method . . . . .   | »    | 70  |
| 1'5.2.  | Manganin wire transducers . . . . .  | »    | 70  |
| 1'6.  | Combination techniques . . . . .   | »    | 72  |
| 1'6.1.  | The immersed-foil technique . . . . .  | »    | 72  |
| 1'6.2.  | The quartz transducer . . . . .  | »    | 73  |
| 1'6.3.  | The laser interferometer technique . . . . .   | »    | 75  |
| 1'7.  | Property of materials measurements . . . . .   | »    | 77  |
| 1'8.  | Conclusions . . . . .  | »    | 78  |
| II. - High-pressure equations of state from shock-wave data.  |  |      |     |
| E. B. ROYCE . . . . .   |  | »    | 80  |
| 2'1.  | The Grüneisen equation of state . . . . .  | »    | 80  |
| 2'2.  | The treatment of shock-wave data . . . . .   | »    | 86  |
| 2'3.  | Electronic and other corrections . . . . .   | »    | 89  |
| 2'4.  | Porous materials . . . . .   | »    | 91  |
| III. - Stability of the electronic configuration in metals at high pressures: The rare earths. E. B. ROYCE. . . . . |  |      |     |
|   |  | »    | 95  |
| 3'1.  | Introduction . . . . .   | »    | 95  |
| 3'2.  | General considerations . . . . .   | »    | 96  |
| 3'3.  | Rare-earth metals . . . . .  | »    | 102 |
| 3'4.  | Conclusions . . . . .  | »    | 105 |
| IV. - Electrical conductivity of condensed media at high pressures. R. N. KEELER . . . . .                          |  |      |     |
|   |  | »    | 106 |
| 4'1.  | Background . . . . .   | »    | 106 |
| 4'2.  | Experimental techniques . . . . .  | »    | 107 |
| 4'3.  | The electrical conductivity of shock-compressed carbon tetrachloride and xenon . . . . . | »    | 114 |
| 4'4.  | Electrical conductivity of shock-compressed metals . . . . .                             | »    | 120 |
| 4'5.  | Geophysical investigations . . . . .   | »    | 122 |
| V. - Properties of magnetic materials under shock compression.  |  |      |     |
| E. B. ROYCE . . . . .   |  | »    | 126 |
| 5'1.  | Introduction . . . . .   | »    | 126 |
| 5'2.  | Experimental procedures . . . . .  | »    | 126 |
| 5'3.  | First-order transitions . . . . .  | »    | 129 |
| 5'4.  | Second-order transitions . . . . .   | »    | 131 |
| 5'5.  | Magnetic anisotropy . . . . .  | »    | 131 |

VI. - New experimental developments in shock wave physics.

R. N. KEELER . . . . . » 138

6'1. X-ray diffraction studies of solids under shock compression » 138

6'1.1. Background . . . . . » 138

6'1.2. Static studies . . . . . » 139

6'1.3. Dynamic studies . . . . . » 143

6'1.4. Future work. . . . . » 144

6'2. Stimulated Brillouin scattering as a diagnostic tool in shock-wave physics. . . . . » 145

J. G. LINHART - Acceleration of projectiles to hypervelocities.

1. Introduction . . . . . » 151

2. Acceleration methods . . . . . » 151

2'1. A dense projectile accelerated by a driver gas . . . . » 152

2'2. Ion or electron beam acceleration of a dense projectile » 155

2'3. Acceleration by a photon beam . . . . . » 158

2'4. Acceleration by electric fields . . . . . » 160

2'5. Acceleration by magnetic fields . . . . . » 161

H. KNOEPFEL - Cumulation of electromagnetic energy.

1. Introduction . . . . . » 168

2. Cylindrical flux compression . . . . . » 170

3. Magnetic-flux losses . . . . . » 173

4. Influence of metal compressibility . . . . . » 175

5. Flux compression by real conductors . . . . . » 178

6. Metal-field interface . . . . . » 179

7. Explosively driven generators . . . . . » 181

J. P. SOMON - Cumulation processes. Self-similar solutions in gas dynamics.

Introduction. . . . . » 189

1. Some processes to reach higher energy densities . . . . » 190

1'1. Interaction of shock waves. Converging shocks . . . . » 190

1'1.1. Head-on collisions . . . . . » 190

1'1.2. Oblique collisions . . . . . » 191

1'1.3. Converging shocks . . . . . » 193

1'2. Collision of moving media. . . . . » 193

1'2.1. Plane geometry . . . . . » 193

1'2.2. Cylindrical and spherical geometries . . . . . » 195

|        |   |          |
|--------|---|----------|
| 1'3.   | Cumulation in a media of variable density . . . . .             | pag. 197 |
| 1'4.   | Sonic cumulation in the cylindrical geometry . . . . .          | » 198    |
| 1'5.   | Magnetohydrodynamic cumulation near a zero-field line . . . . . | » 198    |
| 2.     | Self-similar solutions . . . . .                                | » 199    |
| 2'1.   | Dimensional considerations . . . . .                            | » 199    |
| 2'1.1. | Transformation groups . . . . .                                 | » 200    |
| 2'1.2. | One-dimensional unsteady motion of a perfect gas . . . . .      | » 200    |
| 2'2.   | Some properties of self-similar gas dynamics . . . . .          | » 202    |
| 2'2.1. | The equations . . . . .   | » 202    |
| 2'2.2. | Properties of eq. (17) in the $(Z, V)$ -plane . . . . .         | » 203    |
| 2'3.   | Self-similar cumulation . . . . .                               | » 206    |
| 2'3.1. | Converging motions . . . . .                                    | » 207    |
| 2'3.2. | Converging shock waves . . . . .                                | » 208    |
| 2'3.3. | Collapse of compressible bubbles . . . . .                      | » 212    |
| 2'3.4. | Plane shock wave in a medium of variable density . . . . .      | » 212    |
| 2'4.   | Limitations in cumulation processes . . . . .                   | » 213    |
|        |   |          |
| F. D.  | BENNETT - Vaporization-wave transitions.                        |          |
| 1.     | Introduction . . . . .  | » 217    |
| 2.     | Wave hypothesis . . . . .                                       | » 217    |
| 3.     | Exploding-wire experiments . . . . .                            | » 219    |
| 4.     | Constant-velocity vaporization waves . . . . .                  | » 220    |
| 5.     | Wave speeds from experiments . . . . .                          | » 221    |
| 6.     | Thermodynamic model . . . . .                                   | » 223    |
| 7.     | Comparison of the thermodynamic model with experiment . . . . . | » 227    |
| 8.     | Derivations from the model . . . . .                            | » 228    |
|        |   |          |
| R.     | SCHALL - Detonation physics.                                    |          |
| 1.     | Introduction . . . . .  | » 230    |
| 2.     | Plane detonation waves . . . . .                                | » 231    |
| 2'1.   | The Chapman-Jouguet detonation . . . . .                        | » 231    |
| 2'2.   | Criticism of the C-J theory . . . . .                           | » 234    |
| 3.     | Detonation with curved front . . . . .                          | » 235    |
| 3'1.   | Steady waves . . . . .  | » 235    |
| 3'2.   | Diverging waves . . . . .                                       | » 236    |
| 3'3.   | Converging detonation . . . . .                                 | » 236    |
| 4.     | Wave shaping . . . . .  | » 237    |
| 5.     | Detonation-induced shocks . . . . .                             | » 239    |
| 6.     | High-explosive ballistics . . . . .                             | » 240    |
| 7.     | Determination of shock Hugoniot curves . . . . .                | » 241    |
| 8.     | Shaped charges . . . . .  | » 242    |

ROBERT A. GROSS – The physics of strong shock waves in gases.

|   |      |     |
|---|------|-----|
| 1. Introduction . . . . .                                   | pag. | 245 |
| 2. Fluid dynamic shock wave theory . . . . .                | »    | 246 |
| 2'1. Shock jump relations . . . . .                         | »    | 247 |
| 2'2. Strong-shock theory . . . . .                          | »    | 249 |
| 2'3. Reflected shocks . . . . .                             | »    | 250 |
| 2'4. Shock thickness . . . . .                              | »    | 251 |
| 2'5. Shock power . . . . .                                  | »    | 252 |
| 2'6. Blast waves . . . . .                                  | »    | 253 |
| 3. Ionizing and plasma shock waves . . . . .                | »    | 255 |
| 3'1. Ionizing shock jump relations . . . . .                | »    | 256 |
| 3'2. Ionizing and plasma shock wave thickness . . . . .     | »    | 258 |
| 3'3. Blast waves with ionization . . . . .                  | »    | 261 |
| 3'4. Collisionless shock waves . . . . .                    | »    | 261 |
| 4. Radiative shock waves . . . . .                          | »    | 263 |
| 4'1. Radiative shock equations . . . . .                    | »    | 264 |
| 4'2. Radiative shock jump equations . . . . .               | »    | 268 |
| 5. Relativistic shock waves . . . . .                       | »    | 269 |
| 5'1. Relativistic shock jump relations . . . . .            | »    | 270 |
| 6. Examples of recent research . . . . .                    | »    | 274 |
| 6'1. Thermonuclear detonation wave structure . . . . .      | »    | 274 |
| 6'2. Laboratory strong gas shock wave experiments . . . . . | »    | 275 |

O. N. KROKHIN – High-temperature and plasma phenomena induced by laser radiation. . . . . » 278

|   |   |     |
|---|---|-----|
| 1. An approximate mathematical description of the problem . . . . . | » | 279 |
| 2. An evaporation process . . . . .                                 | » | 283 |
| 3. The process of plasma formation. Plane flow . . . . .            | » | 290 |
| 4. Plasma heating by focused laser radiation . . . . .              | » | 295 |
| 5. Plasma heating by ultrashort laser pulses . . . . .              | » | 299 |

R. E. KIDDER – Interaction of intense photon and electron beams with plasmas.

|  |   |     |
|--|---|-----|
| 1. Introduction . . . . .  | » | 306 |
| 2. Properties of laser beams, plasmas, and their interaction . . . . . | » | 307 |
| 2'1. Properties of focused laser beams . . . . .                       | » | 307 |

|        |   |          |
|--------|---|----------|
| 2'2.   | Linear absorption and reflection of light by a plasma   | pag. 309 |
| 2'2.1. | Reflection and absorption at a sharp plasma boundary . . . . .  | » 311    |
| 2'2.2. | Reflection and absorption at a diffuse plasma boundary . . . . .  | » 312    |
| 2'2.3. | Time required to form a diffuse absorbing layer . . . . .   | » 313    |
| 2'3.   | Heating of plasma ions by electrons: The shortest possible heating time . . . . .   | » 313    |
| 2'4.   | Scaling relations for the production of high-temperature and high-pressure plasmas. . . . .                               | » 314    |
| 3.     | Hydrodynamics of laser-produced plasmas: some simple analytical results . . . . .   | » 315    |
| 3'1.   | Pressure resulting from light-induced blow-off. . . . .   | » 315    |
| 3'2.   | Homogeneous expansion of an isothermal sphere into a vacuum . . . . .   | » 319    |
| 3'3.   | Light-supported detonations. . . . .  | » 322    |
| 4.     | Production of multikilovolt tenth-microgram deuterium or mercury plasmas . . . . .  | » 324    |
| 4'1.   | Laser requirements to produce multikilovolt temperatures in tenth-microgram plasmas . . . . .                             | » 325    |
| 4'2.   | Properties of deuterium and mercury plasmas at 10 keV . . . . .   | » 326    |
| 4'3.   | Results of computer calculations. . . . .   | » 327    |
| 5.     | Nonlinear optical effects in plasmas . . . . .  | » 329    |
| 5'1.   | Single electron nonlinear optical effects. . . . .  | » 330    |
| 5'1.1. | Intensity-dependence of the free-free absorption coefficient . . . . .  | » 330    |
| 5'1.2. | Intensity-dependence of the refractive index . . . . .  | » 335    |
| 5'2.   | Collective nonlinear optical effects . . . . .  | » 338    |
| 5'2.1. | Parametric coupling and excitation of electron optical and electron-ion acoustic modes by an intense light wave . . . . . | » 340    |
| 5'2.2. | Parametric amplification of light waves in a plasma . . . . .   | » 343    |
| 6.     | Plasma heating by means of an intense burst of relativistic electrons . . . . .   | » 347    |
|        |   |          |
| A.     | CARUSO - Interaction of intense light pulses with solid materials.  |          |
| 1.     | Introduction . . . . .  | » 353    |
| 2.     | Irradiation of a massive body by ultrashort laser pulses . . . . .  | » 355    |
| 3.     | Irradiation of solid pellets . . . . .  | » 360    |
| 4.     | Concluding remarks . . . . .  | » 362    |



|  |          |
|--|----------|
| R. GRATTON – Plasma produced by subnanosecond laser pulses.  |          |
| 1. On the experimental test of model. . . . .  | pag. 363 |
| 2. An experiment of plasma production by subnanosecond laser pulses . . . . .  | » 365    |
| 3. Parameters of the plasmas which may be produced by subnanosecond laser pulses focused on large deuterium targets . . . . .  | » 367    |
| F. WINTERBERG – Production of dense thermonuclear plasmas by intense relativistic electron beams.                              |          |
| Introduction. . . . .  | » 370    |
| 1. Conditions for the ignition of a small thermonuclear explosion . . . . .  | » 373    |
| 2. The introduction of the intense relativistic electron beam with the target . . . . .  | » 377    |
| 3. The method of bombarding a target by an intense relativistic electron beam from a pulsed field emission discharge . . . . . | » 381    |
| 4. Converting the energy into useful power . . . . .   | » 393    |
| 5. Rocket propulsion. . . . .  | » 395    |
| 6. The generation of intense ion beams . . . . .   | » 397    |
| E. TELLER – Relativistic hydrodynamics in supernovae. . . . .  | » 402    |