

ITALIAN PHYSICAL SOCIETY

PROCEEDINGS
OF THE
INTERNATIONAL SCHOOL OF PHYSICS
«ENRICO FERMI»

COURSE CIII

edited by P. KIENLE, R.A. RICCI and A. RUBBINO

Directors of the Course

VARENNA ON LAKE COMO

VILLA MONASTERO

23 June - 3 July 1987

*Trends
in Nuclear Physics*

1989



NORTH-HOLLAND
AMSTERDAM - OXFORD - NEW YORK - TOKYO

INDICE

Gruppo fotografico dei partecipanti al Corso	fuori testo
P. KIENLE, R. A. RICCI and A. RUBBINO - Introduction	pag. xv
J. REINHARDT, K. GEIGER, M. GRABIAK, D. C. IONESCU, A. SCHERDIN, S. SCHRAMM, B. MÜLLER and W. GREINER - Positron lines in heavy-ion collisions: recent theoretical de- velopments.	
1. Introduction	» 1
2. Particle production models	» 3
3. Resonant Bhabha scattering	» 6
4. Micropositronium resonances	» 11
5. The polypositronium model	» 14
6. A bag model for an extended new particle	» 15
7. Conclusion	» 18
P. KIENLE - Electron-positron pair creation in heavy-ion col- lisions.	
Introduction	» 22
1. Experimental methods	» 23
2. Positrons induced by a strong, time-changing Coulomb field	» 30
3. Positron lines	» 35
4. Monoenergetic electron-positron pair production	» 47
5. Search for resonant Bhabha scattering	» 52
B. POVH - Quarks, hadrons and nuclei.	
1. The hadronic Trinity	» 59
2. Deep inelastic scattering at Bjorken $x < 0.1$	» 60
3. Hadronic cross-sections and radii	» 62
4. Nuclear force	» 65
5. Conclusions	» 67

M. I. FERRERO - The EMC effect.

1. Introduction	pag.	69
2. Deep inelastic scattering and structure functions	»	70
3. Review of data and interpretation	»	71
4. Future investigations	»	76

T. YAMAZAKI - Hyperon compound nucleus.

1. Introduction	»	78
2. Continuum part in strangeness exchange reactions	»	79
3. Nuclear weak decay of Λ : another source of pions	»	83
4. Recent KEK experiment	»	85
5. Preview: possible hypernuclear spectroscopy following hyperon compound process	»	89

L. NEISE, A. ROSENHAUER, G. PEILERT, H. STÖCKER and W. GREINER - Fragment flow, in-medium effects and the nuclear equation of state.

Introduction	»	92
1. Generalization of the equation of state	»	93
2. Survey about theoretical models	»	97
3. Quantum molecular dynamics	»	100

L. P. CSERNAI - Experimental observables and the nuclear equation of state

»	112	
1. Collective transverse flow	»	113
1'1. An overview of the collective-flow analysis	»	113
1'2. Transverse-momentum analysis	»	116
1'3. Scaling behaviour of transverse flow	»	117
2. Statistical description of multifragmentation	»	121
2'1. Inclusion of interactions at the grand canonical level . .	»	123
2'2. Statistical model with interactions	»	124
2'3. Interactions in mean-field approximation	»	126
2'3.1. Coulomb interaction	»	126
2'3.2. Nuclear interaction	»	126
2'4. Preliminary results	»	129
3. Conclusions	»	131

E. GRÖSSE - Pions and high-energy photons from colliding nuclei.

1. Introduction	»	134
2. Pion production	»	134

3.3. High-energy photons	pag. 138
4. Comparison of photon and pion production	» 142
5. Conclusion and outlook	» 143

S. NAGAMIYA — Nucleus-nucleus collisions in the 10 GeV/nucleon energy regime.

1. Introduction	» 147
1'1. A dilemma in current nuclear physics	» 147
1'2. Phase diagram of nuclear matter	» 148
1'3. Can we create hot and dense matter with heavy-ion beams?	» 149
1'4. Current status at Brookhaven National Laboratory	» 150
2. Pseudo E802 runs in the Fall of 1986	» 152
2'1. Physics goals and experimental set-up	» 152
2'2. ^{16}O beams at the target	» 153
2'3. Energy flow data and their implication	» 154
2'4. Maximum particle density and energy density	» 158
2'5. Summary	» 159
3. Real E802 runs in the Spring of 1987	» 159
3'1. Physics goals	» 159
3'2. E802 set-up	» 161
3'3. Particle identification	» 162
3'4. Results from the April runs	» 163

R. STOCK — Search for the quark-gluon plasma—The NA35 experiment at the CERN SPS.

1. Introduction	» 167
2. Experimental set-up	» 167
3. Experimental results	» 169
3'1. Total inelastic cross-section	» 169
3'2. Energy loss spectrum	» 170
3'3. Charged-particle multiplicities	» 171
3'4. Transverse-energy distribution	» 172
3'5. Dependence of E_T on A_p	» 173
3'6. Dependence of E_T on beam energy	» 174
3'7. Estimates of energy density	» 175
3'8. Dependence of E_T on A_t	» 176
3'9. Rapidity distributions	» 176
3'10. Centre-of-mass angular distributions	» 177
3'11. Average transverse momentum	» 178
3'12. Transverse-momentum distribution	» 178
3'13. Two-pion correlation	» 179
4. Summary and conclusions	» 181
5. Future projects	» 182

I. TALMI — The nuclear shell model—of nucleons or quarks? pag. 185

P. J. TWIN — The evolution of nuclear structure at high spin.

1. Introduction	»	201
2. Shapes and signatures	»	201
2'1. Potential-energy surfaces	»	201
2'2. Level schemes	»	202
2'3. Moment of inertia	»	204
3. Nucleon orbitals and shapes	»	206
3'1. Shape driving orbitals	»	206
3'2. Band termination	»	209
3'3. Quadrupole moments	»	211
4. Decay of the compound nucleus	»	212
4'1. From fusion to the ground state	»	212
4'2. Continuum spectroscopy	»	214
5. Signal to noise	»	215
5'1. TESSA and other multidetector arrays	»	215
5'2. Channel selection	»	218
6. Superdeformation	»	220
6'1. Evidence for superdeformation: ^{152}Dy	»	220
6'2. Feeding and decay	»	223
6'3. The cerium and neodymium nuclei.	»	225
7. Conclusion	»	227

B. HERSKIND and K. SCHIFFER — Superdeformed ^{152}Dy —Population and decay.

1. Introduction	»	231
2. The coexistent shapes in ^{152}Dy	»	233
2'1. Population of superdeformed states	»	233
2'2. Tunnelling and pairing	»	236
3. Simulation calculations	»	239
3'1. The Monte Carlo code	»	239
3'2. Parameters and results	»	241
4. A new experimental technique.	»	245
5. Lifetimes in the superdeformed well	»	248
5'1. Experimental lifetime information	»	248
5'2. Description of the decay times	»	249
5'3. The energy dependence of the mean decay times	»	251
5'4. Simulation of the effective lifetimes	»	253
6. Conclusion	»	255

YU. TS. OGANESSION, YU. V. LOBANOV, M. HUSSONNOIS, YU. P. KHARITONOV, B. GORSKI, O. COSTANTINESCU, A. G. POPEKO, H. BRUCHERTSEIFER, R. N. SAGAIDAK, S. P. TRETYAKOVA, G. V. BUKLANOV, A. V. RYKHLYUK, G. G. GULBEKYAN, A. A. PLEVE †, G. N. IVANOV and V. M. PLOTKO – The experiments aimed at synthesizing element 110.

1. Introduction	pag. 258
2. Experimental procedure and set-up	» 263
3. Study of the kinematic features of incomplete-fusion products from the $^{235,236,238}\text{U} + ^{40}\text{Ar}$ reactions	» 265
4. Experiments aimed at detecting spontaneously fissioning evaporation residues	» 271
5. Control experiments	» 276
6. Radioactive properties	» 278
7. Summary and conclusions	» 279
P. ARMSTRONG – On the production of superheavy elements and the limitations to go beyond.	
1. The new isotopes of the heaviest elements	» 282
2. On the nuclear structure of the heaviest isotopes	» 284
2'1. Mass excesses, shell correction energies and fission barriers	» 285
2'2. Half-lives for α -decay and spontaneous fission	» 287
2'3. Recent theoretical predictions of shell corrections and half-lives	» 290
2'4. What is it, a superheavy nucleus?	» 291
3. On the making of heavy elements	» 293
3'1. Production cross-sections	» 293
3'2. Theoretical predictions on entrance channel limitation	» 295
3'3. Evidence of entrance channel limitation from fusion reactions	» 298
3'4. The concept of fusion probability	» 304
3'5. Comparison to experimental data	» 306
4. Shell effects in collision dynamics	» 312
4'1. Fusion using Pb-like targets	» 312
4'2. Other rearrangement processes involving spherical nuclei	» 312
4'3. The «soft way to element 109»	» 314
4'4. Outlook to make still heavier elements	» 317
MONIQUE BERNAS – On the border of nuclear stability.	
1. Around ^{68}Ni : experiment	» 323
2. Calculations	» 325
3. Deep inelastic transfer	» 327
4. Fission	» 328
5. Conclusion	» 330

M. FUKUGITA — Astrophysical neutrinos and nuclear physics.

1. Introduction	pag. 331
1'1. Particle physics of neutrinos	» 332
1'1.1. Mass of neutrinos	» 332
1'1.2. Générations and neutrino mixings	» 335
1'1.3. Magnetic-dipole moment of neutrinos	» 337
1'1.4. Stability of massive neutrinos	» 339
1'2. Neutrinos in cosmology	» 339
1'2.1. Constraint on the neutrino mass	» 341
1'2.2. Massive neutrinos as dark matter	» 342
1'2.3. Unstable neutrinos	» 343
1'2.4. Heavy « neutrinos »	» 344
1'3. Astrophysical neutrinos	» 345
1'4. Neutrino detectors	» 348
2. Solar-neutrino problems	» 358
2'1. Solar neutrinos	» 358
2'2. Deficit of the ${}^8\text{B}$ neutrino flux	» 361
2'3. Uncertainties in the standard-solar-model prediction	» 361
2'4. Other solar-neutrino problems	» 365
2'5. Modification of the standard scenario—Astrophysics	» 366
2'6. Nonstandard particle properties of neutrinos	» 367
2'6.1. Neutrino oscillations in vacuum	» 367
2'6.2. Neutrino oscillations in matter (Mikheyev-Smirnov-Wolfenstein effect)	» 368
2'6.3. Magnetic-dipole moment of electron-neutrinos	» 373
2'6.4. Neutrino decay	» 374
2'7. Discrimination among scenarios	» 374
2'8. Exotic origins for neutrinos from the Sun	» 375
2'8.1. Neutrinos from the monopole catalysis of the proton decay in the Sun	» 375
2'8.2. Neutrinos from the annihilation of photinos	» 376
3. Neutrinos from supernovae	» 376
3'1. Type-II supernova and neutrinos	» 376
3'2. Brief description of the stellar-core collapse	» 379
3'3. Supernova SN 1987a and the observation of the neutrino burst	» 381
3'4. Progenitor of the supernova	» 383
3'5. Detailed characters of the observed neutrino burst	» 385
3'6. Implications for neutrino physics	» 388
3'6.1. Neutrino stability	» 388
3'6.2. Neutrino mass	» 388
3'6.3. Constraint on the MSW scenario for the solar-neutrino problem	» 389
3'6.4. Number of the neutrino species	» 390
3'6.5. Magnetic moment of neutrinos	» 391
3'7. High-energy neutrinos from a pulsar	» 391
3'8. Perspectives for future supernovae	» 392
4. Miscellaneous neutrino sources	» 394
4'1. Geophysical neutrinos	» 394

4.2. Supernova relic neutrinos	pag. 395
4.3. Atmospheric neutrinos	» 396
5. Conclusion	» 396
Appendix A. - Cross-sections for neutrino scattering	» 397
 C. ROLFS - Experimental quests in nuclear astrophysics.	
1. Introduction	» 417
2. Laboratory approaches	» 419
3. Primordial nucleosynthesis	» 420
3.1. The $^2\text{H}(\text{d}, \gamma)^4\text{He}$ reaction at low energy and the D -state admixture in ^4He	» 420
3.2. Astrophysical S factor of $^3\text{H}(\alpha, \gamma)^7\text{Li}$	» 423
4. Stellar nucleosynthesis	» 425
4.1. Hydrogen burning in massive stars	» 425
4.2. The $^{12}\text{C}(\alpha, \gamma)^{16}\text{O}$ reaction	» 429
4.3. The MgAl cycle	» 432
5. Explosive scenarios	» 434
5.1. Study of $^{22}\text{Na}(\text{p}, \gamma)^{23}\text{Mg}$ via the radioactive-target technique	» 435
5.1.1. Photodisintegration detector	» 435
5.1.2. ^{22}Na target production	» 438
5.2. Study of $^{13}\text{N}(\text{p}, \gamma)^{14}\text{O}$ via the radioactive-ion beam technique	» 439
6. Atomic screening	» 440
 H. MORINAGA - Detection of solar neutrinos.	
1. Introduction	» 445
2. Solar-neutrino flux and spectrum	» 445
3. Possible deformation of the neutrinos' spectrum	» 446
4. Methods of solar-neutrino detection	» 447
5. Davis' experiment	» 448
6. Gallium experiment	» 448
7. ^{205}Tl as a detector for pp neutrinos	» 449
8. Nuclear properties of ^{205}Tl as a neutrino detector	» 449
9. Transition rate problem in case of the threshold detectors	» 449
10. Transition probability problem in the case of the $^{205}\text{Tl}-^{205}\text{Pb}$ detector	» 450
11. The possibility to measure the transition rate experimentally	» 450
12. Higher-energy transitions	» 450
13. Accelerator mass spectrometry	» 451
14. Test experiment to detect ^{205}Pb with accelerator mass spectrometry	» 451
15. Background and geological problems	» 452

16. Geological problems	pag. 452
17. Background problems	» 453
18. Experimental study for estimating various backgrounds	» 453
 C. DÉTRAZ - Some features of nucleus-nucleus collisions at intermediate energies.	
1. About the specifics of intermediate-energy collisions	» 455
2. Peripheral reactions	» 460
2'1. Fragmentationlike processes	» 460
2'1.1. Experimental evidence	» 460
2'1.2. Deviations from a clean-cut fragmentation model	» 466
2'1.3. Calculation of fragmentation products at intermediate energy	» 471
2'2. Transfer reactions	» 477
2'2.1. Experimental evidence	» 477
2'2.2. The selectivity of transfer reactions at intermediate energy	» 478
2'2.3. Identification of collective states at high excitation energies	» 481
3. Central collisions and excited nuclear systems	» 484
3'1. Central collisions as a source of hot nuclei	» 484
3'2. Disappearance of fusion with increasing incident energy	» 485
3'3. Measuring the temperature of excited nuclear systems	» 488
3'3.1. Temperature from the energy spectrum of particles	» 490
3'3.2. Temperature from the ratio of different states	» 492
3'3.3. Other methods and conclusions	» 494
3'4. Developments	» 496
3'4.1. Detailed study of limited hot systems	» 496
3'4.2. Calculating the dynamics of the collision	» 496
3'4.3. The onset of multifragmentation	» 497
4. Synthesis of new nuclear species in intermediate-energy heavy-ion collisions	» 498
4'1. Towards the proton and neutron drip lines	» 499
4'2. Some properties of exotic nuclei	» 501
4'2.1. The search for new radioactive modes	» 501
4'2.2. Binding energies	» 503
5. Final remarks	» 504
 C. GRÉGOIRE - Some aspects of nuclear dynamics.	
1. The Bogoliubov-Born-Green-Kirkwood-Yvon (BBGKY) hierarchy of equations	» 509
1'1. The BBGKY hierarchy	» 511
2. Derivation of a nuclear kinetic equation	» 513
2'1. The Waldmann-Snider equation	» 513
2'2. The Botermans-Malfliet equation	» 515

3.	Wigner transformation and the Landau-Vlasov equation	pag. 517
4.	Approximate solutions of the VE and LVE.	» 520
5.	Phenomenological collision term and simulations.	» 526
6.	Dynamics of heavy-ion collisions.	» 528
7.	Perspectives: fluctuations and dispersions	» 535
C. NGÔ, R. BOISGARD, J. DESBOIS, C. CERRUTI and J. F. MATHIOT – From multifragmentation of nuclei to the quark-gluon plasma.		
PART I. – Multifragmentation.		» 538
1.	Experimental indications of multifragmentation	» 538
2.	Physical picture	» 542
3.	Hot and compressed nuclei	» 544
4.	Study of head-on collisions	» 546
5.	From incomplete fusion to multifragmentation	» 548
PART II. – Quark-gluon plasma formation		» 553
1.	Physical picture	» 553
2.	Results	» 555
	Conclusion	» 559
M. DI TORO – Medium-energy heavy-ion collisions—Phase space models.		
Introduction		» 561
1.	One-body dissipation	» 561
2.	Two-body dissipation	» 563
3.	Excitation of collective states	» 564
4.	From deep inelastic collisions to projectile fragmentation. .	» 565
5.	Properties of the hot source.	» 568
6.	Central collisions: linear-momentum transfer and limits to fusion	» 571
7.	Subthreshold π production	» 572
8.	Conclusion	» 573
N. CINDRO, M. KOROLIJA and R. ČAPLAR – Thermodynamics, reaction mechanisms and the early stages of a nuclear collision.		
1.	Introduction	» 576
2.	Equilibration: the BME approach	» 577

3.	Determination of n_0 : the BME analysis of particle spectra	pag. 579
3'1.	Exclusive spectra	» 579
3'2.	Inclusive spectra. Multisource analysis.	» 580
4.	Results: the constancy of E^*/n_0 :	» 582
R. A. RICCI - Dissipative phenomena and fragmentation in low-energy heavy-ion reactions of medium-mass regions.		
1.	Introduction	» 585
2.	Transitional dissipative mechanisms	» 586
2'1.	» 586
2'2.	» 589
2'3.	» 593
3.	Three-body processes	» 596
P. KIENLE - Closing remarks		» 601