43. Acoustics *(for more detailed headings, see Appendix, Sect. 43)*

43.20.+g General linear acoustics *(see also 03.40.K. Mathematical problems in waves and wave propagation)*

43.25.+y Nonlinear acoustics and macrosonics

43.28.+h Aeroacoustics and atmospheric sound

43.30.+m Underwater sound

43.35.+d Ultrasonics, quantum acoustics, and physical effects of sound

For phonons in crystal lattices, see 63

For plasma acoustics, see 52.35

For low-temperature acoustics and sound in liquid helium, see 67

For ultrasonic relaxation, see 62.80

For acoustical properties of thin films, see 68.60

For surface waves in solids and liquids, see 68.25

For acoustoelectric effects and acoustic wave amplification, see 72.50

For magnetoacoustic effects, oscillations, and resonance, see 75.80

For acousto-optical effects, see 78.20.H

43.40.+s Mechanical vibrations and shock

43.45.+i Statistical studies of acoustical response *(see also 43.55. Architectural acoustics)*

43.50.+y Noise: its effects and control

43.55.+p Architectural acoustics

43.60.+d Acoustic signal processing; acoustic holography

For audition, see 87.34

For speech, see 87.36

43.75.+a Music and musical instruments

For Bioacoustics, see 87.50.C

43.85.+f Acoustical measurements and instrumentation

43.88.+q Transduction; devices for the generation and reproduction of sound

43.90.+v Other topics in acoustics

44. Heat flow, thermal and thermodynamic processes

44.10.+i Heat conduction (models, phenomenological description)

44.25.+f Convective and constrained heat transfer *(see also 47.25.Q. Convection and heat transfer)*

44.30.+v Heat transfer in inhomogeneous media and through interfaces

44.40.+a Radiative heat transfer

44.50.+f Thermal properties of matter (phenomenology, experimental techniques)

44.60.+k Thermodynamic processes (phenomenology, experimental techniques)

44.90.+c Other topics in heat flow, thermal and thermodynamic processes

46. Mechanics, elasticity, rheology

46.10.+z Mechanics of discrete systems *(see also 03.20. General mathematical problems)*

46.20.+e Continuum mechanics *(see also 03.40. General mathematical problems)*

46.30.−i Mechanics of solids and rheology *(see also 62.20. Mechanics of solids, as related to microscopic structure)*

46.30.Cn Static elasticity

46.30.Jv Viscoelasticity, plasticity, viscoplasticity, creep, and stress relaxation (including rheology of solids)

46.30.Lx Static buckling and instability

46.30.My Vibrations, aeroelasticity, hydroelasticity, mechanical waves, and shocks

46.30.Nz Fracture mechanics, fatigue, and cracks

46.30.Pa Friction, wear, adherence, hardness, mechanical contacts

46.30.Rc Measurement methods and techniques

46.60.−a Rheology of fluids and pastes

46.60.Bd Viscoelasticity

46.60.Df Nonlinearities

46.60.Fh Rheopexy, thixotropy

46.90.+s Other topics in mechanics, elasticity, and rheology

47. Fluid dynamics *(for fluid dynamics of quantum fluids, see 67)*

47.10.+g General theory *(see also 03.40.G. Mathematical problems)*

47.15.−x Laminar flows

47.15.Cb Laminar boundary layers

47.15.Fe Stability of laminar flows

47.20.+m Hydrodynamic stability

47.25.−c Turbulent flows, convection, and heat transfer

47.25.Cg Isotropic turbulence

47.25.Fj Boundary layer and shear turbulence

47.25.Jn Turbulent diffusion

47.25.Mr Noise (turbulence generated)

47.25.Qv Convection and heat transfer *(see also 44.25. Convective and constrained heat transfer)*

47.25.Rw Wakes

47.30.+s Rotational flow and vorticity

47.35.+i Hydrodynamic waves

47.40.−x Compressible flows; shock and detonation phenomena *(see also 28.70. Nuclear explosions, 52.35.L. Plasma shock waves)*

47.40.Dc General subsonic flows

47.40.Hg Transonic flows

47.40.Ki Supersonic and hypersonic flows

47.40.Nm Shock-wave interactions

47.45.−n Rarefied gas dynamics *(see also 07.30. Vacuum production and techniques)*

47.45.Dt Free molecular flows

47.45.Gx Slip flows

47.45.Nd Accommodation

47.50.+d Non-Newtonian dynamics

47.55.−t Nonhomogeneous flows

47.55.Bx Cavitation

47.55.Cy Jets

47.55.Ea Nozzles

47.55.Hd Stratified flows

47.55.Kf Multiphase flows

47.55.Mh Flow through porous media

47.60.+i Flows in ducts, channels, and conduits

For biological fluid dynamics, see 87.45

47.65.+a Magnetohydrodynamics and electrohydrodynamics *(for MHD in plasma, see 52.30)*

47.70.−n Reactive, radiative, or nonequilibrium flows

47.70.Fw Chemically reactive flows

47.70.Mc Radiation gas dynamics

47.75.+f Relativistic fluid dynamics

For quantum fluid dynamics, see 67

For geophysical fluid dynamics, see 92

For astrophysical gas dynamics, see 95.30.L

47.80.+v Instrumentation for fluid dynamics *(see also 07.30. Vacuum production)*

47.90.+a Other topics in fluid dynamics

Physics and Astronomy Classification Scheme - 1977

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New York, N.Y. 10017

(ICSU/AB International Classification for Physics)

Indexing articles for physics journals

With the exceptions of Sections 84, 85, and 89 and the fine detail listed in the Appendices, the scheme presented here is the 1977 International Classification for Physics agreed upon for 1977 by the member services of the Abstracting Board (Physics Working Group) of the International Council of Scientific Unions. The hope is that physicists and other users of physics information will eventually encounter only this one common classification scheme in the widest possible spectrum of publications and services.

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- pick no more than four index codes
- designate one of these as the principal index code by placing it *first* in your list
- always choose the lowest-level code available.
  (Third-level codes ending in a "+" sign do not have further sublevels, but those ending in a "-" sign do have sublevels and should only be used if none of the fourth-level codes are appropriate or general enough. Please, examine all the headings at a given level, noting that in cases of apparent overlap the headings are intended to be mutually exclusive, and choose those headings that best seem to fit the substance of your paper.)

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Samuel Schiminovich, *PACS Editor*
A.W. Kenneth Metzner, *Director, Publications Division*

Summary of Scheme

GENERAL

01. Communication, education, history, and philosophy
02. Mathematical methods in physics
03. Classical and quantum physics; mechanics and fields
04. Relativity and gravitation
05. Statistical physics and thermodynamics
06. Measurement science, general laboratory techniques, and instrumentation systems
07. Specific instrumentation of general use in physics

THE PHYSICS OF ELEMENTARY PARTICLES AND FIELDS

11. General theory of fields and particles
12. Specific theories and interaction models; particle systematics
13. Specific reactions and phenomenology
14. Properties of specific particles and resonances

NUCLEAR PHYSICS

21. Nuclear structure
23. Nuclear decay and radioactivity
24. Nuclear reactions and scattering: general
25. Nuclear reactions and scattering: specific reactions
27. Properties of specific nuclei listed by mass ranges
28. Nuclear engineering and nuclear power studies
29. Experimental methods and instrumentation for elementary-particle and nuclear physics

ATOMIC AND MOLECULAR PHYSICS

31. Electronic structure of atoms and molecules, theory
32. Atomic spectra and interactions with photons
33. Molecular spectra and interactions of molecules with photons
34. Atomic and molecular collision processes and interactions
35. Experimentally derived information on atoms and molecules; instrumentation and techniques
36. Studies of special atoms and molecules

CLASSICAL AREAS OF PHENOMENOLOGY (INCLUDING APPLICATIONS)

41. Electricity and magnetism: fields and charged particles
42. Optics
43. Acoustics
44. Heat flow: thermal and thermodynamic processes
46. Mechanics, elasticity, rheology
47. Fluid dynamics

FLUIDS, PLASMAS, AND ELECTRIC DISCHARGES

51. Kinetic and transport theory of fluids; physical properties of gases
52. The physics of plasmas and electric discharges

CONDENSED MATTER: STRUCTURE, MECHANICAL AND THERMAL PROPERTIES

61. Structure of liquids and solids; crystallography
62. Mechanical and acoustical properties of condensed matter
63. Lattice dynamics and crystal statistics
64. Equations of state, phase equilibria, and phase transitions
65. Thermal properties of condensed matter
66. Transport properties of condensed matter (nonelectronic)
67. Quantum fields and solids; liquid and solid helium
68. Surfaces and interfaces; thin films and whiskers

CONDENSED MATTER: ELECTRONIC STRUCTURE, ELECTRICAL, MAGNETIC, AND OPTICAL PROPERTIES

71. Electron states
72. Electronic transport in condensed matter
73. Electronic structure and electrical properties of surfaces, interfaces, and thin films
74. Superconductivity
75. Magnetic properties and materials
76. Magnetic resonances and relaxation in condensed matter; Mössbauer effect
77. Dielectric properties and materials
78. Optical properties and condensed-matter spectroscopy and other interactions of matter with particles and radiation
79. Electron and ion emission by liquids and solids; impact phenomena

CROSS-DISCIPLINARY PHYSICS AND RELATED AREAS OF SCIENCE AND TECHNOLOGY

81. Materials science
82. Physical chemistry
*84. Electromagnetic technology
*85. Electrical and magnetic devices
87. Biophysics, medical physics, and biomedical engineering
*89. Other areas of research of general interest to physicists

GEOPHYSICS, ASTRONOMY, AND ASTROPHYSICS

91. Solid Earth geophysics
92. Hydrospheric and atmospheric geophysics
93. Geophysical observations, instrumentation, and techniques
94. Aeronomy and space physics
95. Fundamental astronomy and astrophysics; instrumentation, techniques, and astronomical observations
96. Solar system
97. Stars
98. Stellar systems; galactic and extragalactic objects and systems; The Universe

***APPENDICES**

02. Mathematical methods in physics
43. Acoustics

**These Sections are outside the ICSU/AB International Classification for Physics*

00. GENERAL

01. Communication, education, history, and philosophy

01.10.−m Announcements, news, and organizational activities

01.10.Cr Announcements, news, and awards
01.10.Fv Conferences, lectures, and institutes
01.10.Hx Physics organizational activities

01.30.−y Physics literature and publications

01.30.Bb Publications of lectures (advanced institutes, summer schools, etc.)
01.30.Cc Conference proceedings
01.30.Ee Monographs and collections
01.30.Kj Handbooks, dictionaries, tables, and data compilations
01.30.Mm Textbooks for graduates and researchers
01.30.Pp Textbooks for undergraduates
01.30.Rr Surveys and tutorial papers; resource letters
01.30.Tt Bibliographies

01.40.−d Education

01.40.Di Course design and evaluation
01.40.Ej Science in elementary and secondary school
01.40.Gm Curricula; teaching methods, strategies, and evaluation
01.40.Jp Teacher training

01.50.−i Educational aids

01.50.Fr Audio and visual aids, films
01.50.Ht Instructional computer use
01.50.Kw Testing theory and techniques
01.50.My Demonstration experiments and apparatus
01.50.Pa Laboratory experiments and apparatus
01.50.Qb Laboratory course design, organization, and evaluation
01.50.Te Buildings and facilities

01.55.+b General physics

01.60.+q Biographical, historical, and personal notes

01.65.+g History of science

01.70.+w Philosophy of science

01.75.+m Science and society

01.90.+g Other topics of general interest

02. Mathematical methods in physics

(for more detailed headings, see Appendix, Sect. 02.)

02.10.+w Algebra, set theory, and graph theory

02.20.+b Group theory *(for algebraic methods in quantum mechanics, see 03.65.F; for symmetries in elementary particle physics, see 11.30)*

02.30.+g Function theory, analysis

02.40.+m Geometry, differential geometry, and topology *(see also 04. Relativity and gravitation)*

02.50.+s Probability theory, stochastic processes, and statistics *(see also 05. Statistical physics)*

02.60.+y Numerical approximation and analysis

02.70.+d Computational techniques *(for data handling and computation, see 06.50)*

02.90.+p Other topics in mathematical methods in physics

03. Classical and quantum physics; mechanics and fields

03.20.+i Classical mechanics of discrete systems: general mathematical aspects *(for applied classical mechanics of discrete systems, see 46.10.; for celestial mechanics, see 95.10.C)*

03.30.+p Special relativity

03.40.−t Classical mechanics of continuous media: general mathematical aspects

03.40.Dz Mathematical theory of elasticity *(see also 46.20. Continuum mechanics, and 46.30. Mechanics of solids)*
03.40.Gc Fluid dynamics: general mathematical aspects *(see also 47. Fluid dynamics)*
03.40.Kf Waves and wave propagation: general mathematical aspects *(see also 46.30.M. Mechanical and elastic waves, 43.20. General linear acoustics)*

03.50.−z Classical field theory

03.50.De Maxwell theory: general mathematical aspects *(for applied classical electrodynamics, see 41)*
03.50.Kk Other special classical field theories

03.65.−w Quantum theory; quantum mechanics *(see also 05.30. Quantum statistical mechanics, for relativistic wave equations, see 11.10.Q)*

03.65.Bz Foundations, theory of measurement, miscellaneous theories
03.65.Ca Formalism
03.65.Db Functional analytical methods
03.65.Fd Algebraic methods *(see also 02.20. Group theory, 33.10.C. Calculational methods in molecular spectroscopy)*
03.65.Ge Solutions of wave equations; bound states
03.65.Nk Scattering theory: nonrelativistic
03.65.Sq Semiclassical theories and applications

For relativistic wave equations, see 11.10.Q

03.70.+k Theory of quantized fields *(see also 11.10. Field theory)*

03.80.+r General theory of scattering *(see also 11.20. S-matrix theory and 11.80. Relativistic scattering)*

04. Relativity and gravitation

For special relativity, see 03.30

04.20.−q General relativity *(see also 02.40. Geometry and topology)*

04.20.Cv Fundamental problems and general formalism
04.20.Fy Canonical formalism, Lagrangians, and variational principles
04.20.Jb Solutions to equations
04.20.Me Conservation laws and equations of motion

04.30.+x Gravitational waves and radiation: theory

04.40.+c Continuous media; electromagnetic and other mixed gravitational systems

04.50.+h Unified field theories and other theories of gravitation

04.60.+n Quantum theory of gravitation

For relativistic astrophysics, see 95.30.S

For relativistic cosmology, see 98.80.D

04.80.+z Experimental tests of general relativity and observations of gravitational radiation

04.90.+e Other topics in relativity and gravitation

05. Statistical physics and thermodynamics *(see also 02.50. Probability theory, stochastic processes, and statistics)*

05.20.−y Statistical mechanics

05.20.Dd Kinetic theory
05.20.Gg Classical ensemble theory

05.30.−d Quantum statistical mechanics *(see also 67. Quantum fluids and 71. Electron states in condensed matter)*

05.30.Ch Quantum ensemble theory
05.30.Fk Fermion systems and electron gas
05.30.Jp Boson systems

05.40.+j Fluctuation phenomena, random processes, and Brownian motion

05.50.+q Lattice theory and statistics; Ising problems *(see also 64.60.C. Order disorder and statistical mechanics of model systems; 75.10.H. Ising models)*

05.60.+w Transport processes: theory

05.70.−a Thermodynamics *(see also 64. Equations of state, phase equilibria, and phase transitions; 65. Thermal properties of condensed matter; for chemical thermodynamics, see 82.60)*

05.70.Ce Thermodynamic functions and equations of state
05.70.Fh Phase transitions: general aspects
05.70.Jk Critical point phenomena
05.70.Ln Nonequilibrium thermodynamics, irreversible processes *(see also 31.70.F. Potential energy surfaces, 82. Physical chemistry)*

05.90.+m Other topics in statistical physics and thermodynamics

06. Measurement science, general laboratory techniques, and instrumentation systems

06.20.−f Metrology

06.20.Dk Measurement and error theory
06.20.Fn Units
06.20.Hq Measurement standards
06.20.Jr Determination of fundamental constants

06.30.−k Measurement of basic quantities

06.30.Bp Measurement of spatial parameters
06.30.Dr Mass and density measurement
06.30.Ft Time and frequency measurement
06.30.Gv Velocity and acceleration measurement
06.30.Lz Measurement of basic electromagnetic quantities

06.50.−x Data handling and computation

06.50.Dc Data gathering, processing, and recording; data displays
06.50.Mk Computing devices and techniques

06.60.−c Laboratory techniques

06.60.Ei Sample preparation
06.60.Jn High-speed techniques (microsecond to picosecond)
06.60.Sx Micromanipulators, micropositioners, and microtomes
06.60.Vz Workshop techniques (welding, machining, lubrication, bearings, etc.)
06.60.Wa Safety *(see also 28.80.F. Radiation monitoring and protection; 87.60.M. Radiation dosimetry, 87.60.P Radiation protection)*

06.70.−h General instrumentation

06.70.Dn Sensing and detecting devices
06.70.Ep Testing equipment
06.70.Hs Display, recording, and indicating instruments
06.70.Mx Transducers
06.70.Td Servo and control devices

06.90.+v Other topics in measurement science, general laboratory techniques and instrumentation systems

07. Specific instrumentation and techniques of general use in physics *(see also within each subdiscipline for specialized instrumentation and techniques)*

07.10.+i Mechanical instruments and measurement methods

07.20.−n Thermal instruments and techniques

07.20.Dt Thermometry
07.20.Fw Calorimetry
07.20.Hy Furnaces
07.20.Ka High-temperature techniques and instrumentation; pyrometry
07.20.Mc Cryogenics

07.25.+f Hygrometry

07.30.−t Vacuum production and techniques *(see also 47.45. Rarefied gas dynamics, 47.80. Fluid dynamics instrumentation)*

07.30.Bx Evacuating power, degasification, residual gas
07.30.Cy Vacuum pumps
07.30.Dz Vacuum meters
07.30.Hd Vacuum apparatus and testing methods
07.30.Kf Auxiliary apparatus, hardware, and materials

07.35.+k High-pressure production and techniques

07.50.+f Electrical instruments and techniques

07.55.+x Magnetic instruments and techniques

07.58.+g Magnetic resonance spectrometers, auxiliary instruments, and techniques *(see also 61.16.H. EPR and NMR determinations)*

07.60.−j Optical instruments and techniques *(for radiation detection, see 07.62; for spectroscopy and spectrometers, see 07.65)*

07.60.Dq Photometry, radiometry, colorimetry
07.60.Fs Polarimetry and ellipsometry
07.60.Hv Refractometry and reflectometry
07.60.Ly Interferometry
07.60.Pb Optical microscopy

07.62.+s Detection of radiation (bolometers, photoelectric cells, infrared and submillimeter wave detection)

07.65.−b Optical spectroscopy and spectrometers *(see also 07.85. for x-ray spectroscopy)*

07.65.Eh Visible and ultraviolet spectroscopy and spectrometers
07.65.Gj Infrared spectroscopy and spectrometers

07.68.+m Photography, photographic instruments and techniques

07.75.+h Mass spectrometers and mass spectrometry techniques

07.77.+p Particle beam production and handling; targets *(see also 41.80. Particle beam optics and 29.25. —in elementary-particle and nuclear physics)*

07.80.+x Electron and ion microscopes and techniques *(see also in condensed matter, 61.16.D. Electron microscopy; 61.16.F. Field ion microscopy)*

For radiation spectrometers and spectroscopic techniques, see 29.30

For radiation measurement, detection, and counting, see 29.70

07.85.+n X- and γ-ray instruments and techniques

07.90.+c Other topics in specialized instrumentation

10. THE PHYSICS OF ELEMENTARY PARTICLES AND FIELDS

(FOR COSMIC RAYS, SEE 92; FOR EXPERIM. METHODS AND INSTRUMENTATION, SEE 29)

11. General theory of fields and particles *(see also 03.65. Quantum theory, 03.70. Theory of quantized fields, 03.80. General theory of scattering)*

11.10.−z Field theory

11.10.Cd Axiomatic approach
11.10.Ef Lagrangian and Hamiltonian approach
11.10.Gh Renormalization
11.10.Jj Asymptotic problems and properties
11.10.Lm Nonlinear or nonlocal theories and models
11.10.Mn Schwinger source theory
11.10.Np Gauge field theories
11.10.Qr Relativistic wave equations
11.10.St Bound and unstable states; Bethe–Salpeter equations

11.20.−e *S*-matrix theory

11.20.Dj Scattering matrix and perturbation theory
11.20.Fm Dispersion relations and analytic properties of the *S* matrix

11.30.−j Symmetry and conservation laws *(see also 02.20. Group theory)*

11.30.Cp Lorentz and Poincaré invariance
11.30.Er Charge conjugation, parity, time reversal, and other discrete symmetries
11.30.Jw SU(2) and SU(3) symmetries
11.30.Kx SU(4) symmetry
11.30.Ly Other internal and higher symmetries
11.30.Na Nonlinear and dynamical symmetries (spectrum-generating symmetries)
11.30.Pb Supersymmetry
11.30.Qc Spontaneous symmetry breaking
11.30.Rd Chiral symmetries

11.40.−q Currents and their properties

11.40.Dw General theory of currents
11.40.Fy Lagrangian approach to current algebras
11.40.Ha Partially conserved axial-vector currents

11.50.−w Dispersion relations and sum rules

11.50.Ec *N*/*D* method
11.50.Ge Bootstraps
11.50.Jg Crossing symmetries
11.50.Li Sum rules
11.50.Nk Multivariable dispersion relations (including Mandelstam representation)

11.60.+c Complex angular momentum; Regge formalism *(see also 03.80. General theory of scattering, 12.40.M —in strong interactions)*

11.80.−m Relativistic scattering theory *(see also 03.80. General theory of scattering)*

11.80.Cr Kinematical properties (helicity and invariant amplitudes, kinematic singularities, etc.)

11.80.Et Partial-wave analysis

11.80.Fv Approximations (eikonal approximation, variational principles, etc.)

11.80.Gw Multichannel scattering

11.80.Jy Many-body scattering and Faddeev equation

11.80.La Multiple scattering

11.90.+t Other topics in general field and particle theory

12. Specific theories and interaction models; particle systematics

12.20.−m Electromagnetic and unified gauge fields

12.20.Ds Specific calculations and limits of quantum electrodynamics

12.20.Fv Experimental tests of quantum electrodynamics

12.20.Hx Unified field theories and models

12.25.+e Models for gravitational interactions *(see also 04.60. Quantum theory of gravitation)*

12.30.−s Models of weak interactions

12.30.Cx Neutral currents

12.30.Ez Intermediate bosons

12.40.−y Models of strong interactions

12.40.Bb Composite models of the structure of hadrons (general models, dynamics, schemes for confinement)

12.40.Cc Properties of hadrons derived from the composite models

12.40.Ee Statistical models

12.40.Ff Bootstrap models

12.40.Hh Duality and dual models

12.40.Kj Hadron classification schemes

12.40.Mm Complex angular momentum plane; Regge poles and cuts (Reggeons) *(see also 11.60. —for general theory)*

12.40.Pp Absorptive, optical, and eikonal models

12.40.Qq Potential models

12.40.Rr Peripheral models (one or more particle exchange)

12.40.Ss Multiperipheral and multi-Regge models

12.40.Vv Vector-meson dominance

12.70.+q Hadron mass formulas

12.90.+b Miscellaneous theoretical ideas and models

13. Specific reactions and phenomenology

13.10.+q Weak and electromagnetic interactions of leptons (including interactions involving cosmic rays)

13.15.+g Neutrino interactions (including reactions involving cosmic rays)

13.20.−v Leptonic and semileptonic decays of mesons

13.20.Cz π decays

13.20.Eb K decays

13.20.Jf Other meson decays (ψ, J, etc.)

13.25.+m Hadronic decays of mesons

13.30.−a Decays of baryons

13.30.Ce Leptonic and semileptonic decays

13.30.Eg Hadronic decays

13.40.−f Electromagnetic processes and properties of hadrons

13.40.Dk Electromagnetic mass differences

13.40.Fn Electromagnetic form factors; electric and magnetic moments

13.40.Hq Electromagnetic decays

13.40.Ks Electromagnetic corrections to strong- and weak-interaction processes

13.60.−r Photon and charged-lepton interactions with hadrons *(for neutrino interactions, see 13.15)*

13.60.Fz Elastic and Compton scattering

13.60.Hb Total and inclusive cross sections (including deep-inelastic processes)

13.60.Kd Meson production

13.60.Mf Meson-resonance production

13.60.Rj Baryon and baryon-resonance production

13.65.+i Hadron production by electron–positron collisions

13.75.−n Hadron-induced low- and intermediate-energy reactions and scattering, energy $\leq$ 10 GeV *(for higher energies, see 13.85)*

13.75.Cs Nucleon–nucleon interactions, including antinucleon, deuteron, etc. (energy $\leq$ 10 GeV) *(for N–N interactions in nuclei, see 21.30)*

13.75.Ev Hyperon–nucleon interactions (energy $\leq$ 10 GeV)

13.75.Gx Pion–baryon interactions (energy $\leq$ 10 GeV)

13.75.Jz Kaon–baryon interactions (energy $\leq$ 10 GeV)

13.75.Lb Meson–meson interactions (energy $\leq$ 10 GeV)

13.85.−t Hadron-induced high- and super-high-energy interactions, energy > 10 GeV *(for low energies, see 13.75)*

13.85.Dz Elastic scattering (energy > 10 GeV)

13.85.Fb Inelastic scattering, two-particle final states (energy > 10 GeV)

13.85.Hd Inelastic scattering, many-particle final states (energy > 10 GeV)

13.85.Kf Inclusive reactions, including total cross sections (energy > 10 GeV)

13.85.Mh Cosmic ray interactions (energy > 10 GeV) *(see also 94.40. Cosmic rays)*

13.90.+i Other topics in specific reactions and phenomenology of elementary particles

14. Properties of specific particles and resonances

14.20.−c Baryons and baryon resonances (including antiparticles)

14.20.Cg Neutrons

14.20.Ei Protons

14.20.Gk Baryon resonances with $S=0$

14.20.Jn Hyperons and hyperon resonances

14.40.−n Mesons and meson resonances

14.40.Dt π mesons

14.40.Fw K mesons

14.40.Ka ρ, ω, and η mesons

14.40.Mc A and B mesons

14.40.Pe Other heavy mesons (ψ, J, etc.)

14.60.−z Leptons

14.60.Cd Electrons and positrons

14.60.Ef Muons

14.60.Gh Neutrinos

14.80.−j Other and hypothetical particles

14.80.Dq Quarks

14.80.Fs Intermediate bosons

14.80.Hv Magnetic monopoles

14.80.Kx Others (including photons and tachyons)

20. NUCLEAR PHYSICS

21. Nuclear structure

21.10.−k General and average properties of nuclei; properties of nuclear energy levels *(for properties of specific nuclei listed by mass ranges, see 27)*

21.10.Dr Binding energy and masses

21.10.Ft Shape, charge, and radius

21.10.Hw Spin, parity, and isobaric spin

21.10.Jx Spectroscopic factors

21.10.Ky Electromagnetic moments

21.10.Ma Level density and structure

21.10.Pc Single particle structure in levels

21.10.Re Collective structure in levels (including rotational bands)

21.10.Sf Coulomb effects

21.30.+y Nuclear forces *(see also 13.75.C. Nucleon–nucleon interactions)*

21.40.+d Few-nucleon systems

21.60.−n Nuclear-structure models and methods

21.60.Cs Shell model

21.60.Ev Collective models

21.60.Fw Models based on group theory

21.60.Gx Cluster models

21.60.Jz Hartree–Fock and random-phase approximations

21.65.+f Nuclear matter

For hadronic atoms and molecules, see 36.10.G

21.80.+a Hypernuclei

21.90.+f Other topics in nuclear structure

23. Nuclear decay and radioactivity *(see also 82.55. Radiochemistry)*

23.20.−g Electromagnetic transitions

23.20.Ck Lifetimes and transition probabilities
23.20.En Angular distribution and correlation measurements
23.20.Gq Multipole mixing ratios
23.20.Js Multipole matrix elements
23.20.Lv Gamma transitions and level energies
23.20.Nx Internal conversion and extranuclear effects

23.40.−s β decay; electron and muon capture

23.40.Bw Weak interaction and lepton aspects of beta decay
23.40.Hc Nuclear matrix elements and nuclear structure inferred from beta decay

23.60.+e α decay

23.90.+w Other topics in nuclear decay and radioactivity

24. Nuclear reactions and scattering: general

24.10.−i Nuclear reaction and scattering models and methods

24.10.Dp Coupled-channel and many-body-theory methods
24.10.Fr Plane- and distorted-wave Born approximations
24.10.Ht Optical and diffraction models

24.30.−v Resonance reactions and scattering

24.30.Cz Giant resonances
24.30.Eb Isobaric analog resonances

24.50.+g Direct reactions and scattering

24.60.+m Statistical theory and fluctuations

24.70.+s Polarization in reactions and scattering

24.75.+i General properties of fission

24.90.+d Other topics in nuclear reactions and scattering: general

25. Nuclear reactions and scattering: specific reactions

25.10.+s Nuclear reactions and scattering involving few-nucleon systems

25.20.+y Photonuclear reactions and photon scattering

25.30.−c Lepton-induced reactions and scattering

25.30.Cg Electron and positron scattering
25.30.Ei Muon scattering
25.30.Gk Neutrino scattering

25.40.−h Nucleon-induced reactions and scattering *(see also 28.20. Neutron physics)*

25.40.Cm Elastic proton scattering
25.40.Dn Elastic neutron scattering
25.40.Ep Inelastic proton scattering and (p, n) reactions
25.40.Fq Inelastic neutron scattering and (n, p) reactions
25.40.Gr Single nucleon transfer reactions
25.40.Jt Few nucleon transfer reactions
25.40.Lw Radiative capture
25.40.Rb Reactions and scattering above meson production thresholds (energies >400 MeV)

25.50.−n ^{2}H- and ^{3}H-induced reactions and scattering

25.50.Dt Elastic and inelastic scattering
25.50.Gx Single-nucleon transfer reactions
25.50.Jz Few nucleon transfer reactions

25.60.−t ^{3}He- and ^{4}He-induced reactions and scattering

25.60.Cy Elastic and inelastic scattering
25.60.Ea Single-nucleon transfer reactions
25.60.Fb Few nucleon transfer reactions

25.70.−z Heavy-particle-induced reactions and scattering

25.70.Bc Reaction mechanisms
25.70.De Few nucleon transfers
25.70.Fg Bulk matter and collective aspects of heavy-ion reactions
25.70.Hi Elastic, inelastic, and charge exchange reactions
25.70.Kk Coulomb excitation

25.80.+f Meson- and hyperon-induced reactions and scattering

25.85.−w Fission reactions

25.85.Ca Spontaneous fission
25.85.Ec Neutron-induced fission
25.85.Ge Charged-particle-induced fission
25.85.Jg Photofission

25.90.+k Other topics in nuclear reactions and scattering: specific reactions

27. Properties of specific nuclei listed by mass ranges *(an additional heading must be chosen with these entries, where the given mass number limits are, to some degree, arbitrary)*

27.10.+h $A \leq 5$

27.20.+n $6 \leq A \leq 19$

27.30.+t $20 \leq A \leq 38$

27.40.+z $39 \leq A \leq 58$

27.50.+e $59 \leq A \leq 89$

27.60.+j $90 \leq A \leq 149$

27.70.+q $150 \leq A \leq 189$

27.80.+w $190 \leq A \leq 219$

27.90.+b $220 \leq A$

28. Nuclear engineering and nuclear power studies

28.20.−v Neutron physics *(see also 25.40. Nucleon-induced reactions and scattering)*

28.20.Cz Neutron scattering
28.20.Fc Neutron absorption
28.20.He Neutron diffusion
28.20.Lh Neutron moderation

28.40.−f Nuclear reactors

28.40.Dk Theory and design
28.40.Gp Nuclear reactor materials
28.40.Ks Cooling and heat recovery
28.40.Nw Experiments with nuclear reactors

28.45.−x Operation of nuclear reactors

28.45.Cb Pile control and guidance
28.45.Ed Protection systems, safety, and accidents
28.45.Gf Fuel preparation and reprocessing
28.45.Jh Residues: processing, storage, removal, use

28.50.−k Specific types of reactors, reactor applications

28.50.Dr Research reactors
28.50.Ft Fast and breeder reactors
28.50.Hw Power and production reactors
28.50.Ky Propulsion reactors
28.50.Ma Auxiliary generators and electric propulsion
28.50.Pc Power plants, desalting plants
28.50.Re Fusion reactors and thermonuclear power studies *(see also 52.55.P. Confinement in fusion reactors)*

28.60.+s Isotope separation and enrichment

28.70.+y Nuclear explosions *(see also 47.40. Shock and detonation phenomena)*

28.80.−c Radiation technology, including shielding *(see also 87.60. Medical and biomedical uses of fields, radiations, and radioactivity)*

28.80.Cg Dosimetry
28.80.Fj Radiation monitoring and radiation protection

28.90.+i Other topics in nuclear engineering and nuclear power studies

29. Experimental methods and instrumentation for elementary-particle and nuclear physics

29.10.+y Preacceleration (injection)

29.15.−n Electrostatic, collective, and linear particle accelerators

29.15.Br Electrostatic accelerators
29.15.Dt Linear accelerators (including electron ring accelerators)

29.20.−c Cyclic accelerators and storage facilities

29.20.Dh Storage rings
29.20.Fj Betatrons
29.20.Hm Cyclotrons
29.20.Jn Synchrocyclotrons
29.20.Lq Synchrotrons

For plasma accelerators, see 52.75.D

29.25.−t Particle sources and targets; preparation and technology *(see also 07.72. General instrumentation)*

29.25.Bx Electron sources
29.25.Cy Ion sources: positive, negative, and polarized
29.25.Dz Neutron sources
29.25.Ea Radioactive sources
29.25.Fb Beam handling, focusing, pulsing, stripping, etc.
29.25.Gc Nuclear bombardment targets
29.25.Kf Polarized targets

29.30.−h Radiation spectrometers and spectroscopic techniques

29.30.Dn Heavy charged-particle spectroscopy
29.30.Ep α-ray spectroscopy
29.30.Fq β-ray spectroscopy
29.30.Hs Neutron spectroscopy
29.30.Kv X- and γ-ray spectroscopy

29.40.−n Radiation detectors

29.40.Br Ionization chambers
29.40.Dt Cloud chambers
29.40.Fw Bubble chambers
29.40.Hy Spark chambers and other track chambers
29.40.Ka Cherenkov detectors
29.40.Mc Scintillation detectors; scintillators and photomultipliers
29.40.Pe Semiconductor detectors
29.40.Rg Nuclear emulsions
29.40.Sh Geiger tubes
29.40.Ti Position sensitive detectors

For mass spectrometers, see 07.75

29.60.−z Counting circuits and nuclear electronics

29.60.Cd Basic function units: supply units, amplifiers, etc.
29.60.Ef Pulse counting assemblies: counting scalers, analyzers, etc.
29.60.Gh Pulse circuits
29.60.Jj Radiation monitors

29.70.−e Radiation measurement, detection, and counting *(see also 29.30. Radiation spectrometers and spectroscopy, 29.40. Radiation detectors)*

29.70.Dj Angular correlation techniques
29.70.Fm Coincidence techniques *(see also 06.60.Q. General laboratory techniques)*
29.70.Gn Energy loss and energy range relations
29.70.Jq Integral methods of radiation detection

For dosimetry, see 87.60.M

29.75.+x Polarization analysis

29.80.−j Nuclear information processing

29.80.Cp Computer systems
29.80.Fs Programming

29.90.+r Other topics in high-energy and nuclear experimental methods and instrumentation

30. ATOMIC AND MOLECULAR PHYSICS *(FOR PHYSICAL CHEMISTRY, SEE 82)*

31. Electronic structure of atoms and molecules: theory *(see also 71. Electron states in solids)*

31.10.+z General theory of electronic structure, electronic transitions, and chemical binding

31.15.+q General mathematical and computational developments

31.20.−d Specific calculations and results

31.20.Di Complete ab initio calclations (exact or nearly exact calculations on small species)
31.20.Ej Ab initio LCAO and GO SCF calculations
31.20.Gm Other accurate, or nearly ab initio calculations (DIM method, SAMO method, etc.)
31.20.Lr Statistical model calculations (Thomas–Fermi and Thomas–Fermi–Dirac models)
31.20.Nt Semi-empirical NDO calculations (CNDO, INDO, MINDO, PCILO methods, etc.)
31.20.Pv Other semi-empirical calculations (Hückel, generalized Hückel, PPP methods, etc.)
31.20.Rx Valence bond calculations (ab initio or not)
31.20.Tz Electron correlation and CI calculations
31.20.Wb Empirical methods (nonquantum methods for conformations, as Wiberg method, Westheimer method, etc.)

31.30.−i Corrections to electronic structure

31.30.Gs Hyperfine interactions and isotope effects
31.30.Jv Radiative and relativistic effects

31.50.+w Excited states

31.70.−f Effects of molecular interactions on electronic structure *(see also 34. Atomic and molecular interactions)*

31.70.Dk Environmental and solvent effects
31.70.Fn Potential energy surfaces for chemical reactions and collisions *(see also 82.20.K.—in chemical kinetics; 34.20. Intermolecular forces; for beam studies, see 34.50.L)*
31.70.Hq Time-dependent phenomena: excitation and relaxation processes, and reaction rates *(see also 34. Atomic and molecular collisions)*
31.70.Ks Molecular solids

31.90.+s Other topics in the theory of the electronic structure of atoms and molecules (including properties other than the energy)

32. Atomic spectra and interactions with photons

32.30.−r Atomic spectra, grouped by wavelength ranges

32.30.Bv Radiofrequency, microwave, and infrared spectra (including magnetic resonance spectra)
32.30.Jc Visible and ultraviolet spectra *(for fluorescence and phosphorescence spectra, see 32.50)*
32.30.Rj X-ray spectra

32.50.+d Fluorescence, phosphorescence (including quenching) *(for quenching processes, see also 34.)*

32.60.+i Zeeman and Stark effects

32.70.−n Intensities and shapes of atomic spectral lines

32.70.Cs Oscillator strengths, transition moments
32.70.Fw Lifetimes, absolute and relative intensities
32.70.Jz Line shapes, widths, and shifts

32.80.−t Atomic photon processes

32.80.Bx Level crossing and optical pumping
32.80.Dz Autoionization
32.80.Fb Photoionization and photodetachment
32.80.Hd Auger effect and inner-shell ionization
32.80.Kf Multiphoton processes

32.90.+a Other topics in atomic spectra and interactions of atoms with photons

33. Molecular spectra and interactions of molecules with photons

33.10.−n Calculation of molecular spectra

33.10.Cs Calculational methods (including new theoretical techniques and applications of group theory) *(see also 03.65.F. Algebraic methods in quantum mechanics)*
33.10.Ev Rotational analysis
33.10.Gx Vibrational analysis
33.10.Jz Vibration-rotational analysis
33.10.Lb Vibronic, rovibronic, and rotation–electron-spin interactions

33.20.−t Molecular spectra, grouped by wavelength ranges *(for photoelectron spectra, see 33.60)*

33.20.Bx Radio-frequency and microwave spectra *(for NMR spectra, see 33.25; for EPR spectra, see 33.35)*

33.20.Ea Infrared spectra

33.20.Fb Raman and Rayleigh spectra (including optical scattering)

33.20.Kf Visible spectra

33.20.Lg Ultraviolet spectra

33.20.Ni Vacuum ultraviolet spectra

33.20.Rm X-ray spectra

33.25.−j Nuclear magnetic resonance and relaxation

33.25.Bn Relaxation phenomena

33.25.Dq Chemical shifts

33.25.Fs Nuclear spin interactions and quadrupole effects

33.25.Hv Chemically induced dynamic nuclear polarization (CIDNP)

33.30.+a Nuclear quadrupole resonance (NQR)

33.35.−q Electron paramagnetic resonance (EPR) and relaxation

33.35.Cv Relaxation phenomena

33.35.Ex EPR spectra

33.35.Gz Chemically induced dynamic electron polarization (CIDEP)

33.40.−e Double resonances and other multiple resonances

33.40.Ci Double nuclear magnetic resonance (DNMR), electron-nuclear double resonance (ENDOR), and electron double resonance (ELDOR)

33.40.Hp Microwave optical double resonance spectroscopy (MODOR) and phosphorescence microwave double resonance spectroscopy (PMDR)

33.45.+x Mössbauer spectra

33.50.−j Fluorescence, phosphorescence, radiationless transitions (intersystem crossing, internal conversion) *(for quenching processes, see also 34)*

33.50.Dq Fluorescence and phosphorescence spectra

33.50.Hv Radiationless transitions

33.55.+c Zeeman and Stark effects; magneto-optical and electro-optical spectroscopy; circular dichroism

33.60.−q Photoelectron spectra

33.60.Cv Ultraviolet and vacuum-ultraviolet photoelectron spectra

33.60.Fy X-ray photoelectron spectra

33.70.−w Intensities and shapes of molecular spectral lines and bands

33.70.Ca Oscillator and band strengths, transition moments, and Franck–Condon factors

33.70.Fd Lifetimes, absolute and relative line and band intensities

33.70.Jg Line and band widths, shapes, and shifts

33.80.−b Molecular photon processes

33.80.Be Level crossing and optical pumping

33.80.Eh Autoionization, photoionization, and photodetachment

33.80.Gj Diffuse spectra; predissociation, photodissociation

33.80.Kn Multiphoton processes

33.90.+h Other topics in molecular spectra and molecular interactions with photons

34. Atomic and molecular collision processes and interactions

34.10.+x General theories and models (including statistical theories, transition state, stochastic and trajectory models, etc.)

34.20.−b Interatomic and intermolecular potentials and forces

34.20.Be General potential functions and intermediate-range forces *(see also 31.70.F and 82.20.K for potential energy surfaces)*

34.20.Fi Long-range forces

34.20.Kn Short-range forces

For molecular solids, see 31.70.K

34.40.+n Elastic scattering of atoms and molecules

34.50.−s Inelastic scattering of atoms and molecules

34.50.Ez Rotational and vibrational energy transfer

34.50.Hc Electronic excitation and ionization (including beam-foil excitation and ionization)

34.50.Lf Chemical reactions, energy disposal, and angular distribution, as studied by atomic and molecular beams *(see also 31.70.F and 82.20.K for potential-energy surfaces, 82.40.D. Beam reactions)*

34.70.+e Charge transfer *(see also 82.30.F. Charge transfer reactions)*

34.80.−i Electron scattering

34.80.Bm Elastic scattering of electrons by atoms and molecules

34.80.Dp Atomic excitation and ionization by electron impact

34.80.Gs Molecular excitation, ionization, and dissociation by electron impact

34.90.+q Other topics in atomic and molecular collision processes and interactions

35. Experimentally derived information on atoms and molecules; instrumentation and techniques

35.10.−d Atoms

35.10.Bg Atomic masses, mass spectra, abundances, and isotopes *(for mass spectrometry, see also 07.75)*

35.10.Di Electric and magnetic moments, polarizability

35.10.Fk Relativistic corrections, fine- and hyperfine-structure constants

35.10.Hn Ionization potentials, electron affinities

35.20.−i Molecules *(see also 61.55, 61.60, and 61.65 for specific structures of elements and alloys, of other inorganic materials, and of organic materials, respectively)*

35.20.Bm General molecular conformation and symmetry; stereochemistry

35.20.Dp Interatomic distances and angles

35.20.Gs Bond strengths, dissociation energies, hydrogen bonding, etc.

35.20.Jv Barrier heights (internal rotation, inversion); rotational isomerism, conformational dynamics

35.20.My Electric and magnetic moments (and derivatives), polarizability, and magnetic susceptibility

35.20.Pa Rotation, vibration, and vibration-rotation constants

35.20.Sd Hyperfine- and fine-structure constants

35.20.Vf Ionization potentials, electron affinities, molecular core binding energy

35.20.Wg Mass spectra

35.20.Yh Correlation times in molecular dynamics

35.80.+s Atomic and molecular measurement and techniques

36. Studies of special atoms and molecules

36.10.−k Exotic atoms and molecules (containing mesons, muons, and other abnormal particles)

36.10.Dr Positronium, muonium, muonic atoms and molecules

36.10.Gv Mesonic atoms and molecules, hyperonic atoms and molecules

36.20.−r Macromolecules and polymer molecules *(for polymer reactions and polymerization, see 82.35; for biological macromolecules and polymers, see also 87.15)*

36.20.Cw Molecular weights, dispersity

36.20.Ey Conformation (statistics and dynamics)

36.20.Fz Constitution (chains, sequences)

36.20.Hb Configuration (bonds, dimensions)

36.20.Kd Electronic structure and spectra

36.40.+d Atomic and molecular clusters

36.90.+f Other special atoms and molecules

40. CLASSICAL AREAS OF PHENOMENOLOGY (INCLUDING APPLICATIONS)

41. Electricity and magnetism: fields and charged particles

41.10.−j Classical electromagnetism

For Maxwell theory, see 03.50.D

41.10.Dq Electrostatics, magnetostatics

41.10.Fs Steady-state electromagnetic fields; electromagnetic induction

41.10.Hv Electromagnetic waves: theory

41.70.+t Particles in electromagnetic fields: classical aspects (including synchrotron radiation)

41.80.−y Particle beams and particle optics *(see also 07.80. Electron and ion microscopy, 07.72. Beam handling equipment)*

41.80.Dd Electron beams and electron optics

41.80.Gg Ion beams and ion optics

41.90.+e Other topics in electricity and magnetism

42. Optics *(for properties of gases and of liquids and solids see 51.70 and 78, respectively)*

42.10.−s Propagation and transmission in homogeneous media

42.10.Dy Wave-front and ray tracing

42.10.Fa Edge and boundary effects, refraction

42.10.Hc Diffraction and scattering from extended bodies

42.10.Jd Interference

42.10.Ke Absorption

42.10.Mg Coherence

42.10.Nh Polarization

42.10.Qj Propagation and transmission in homogeneous and anisotropic media, birefringence

42.20.−y Propagation and transmission in inhomogeneous media

42.20.Cc Wave front, ray tracing, and beam spread in random turbulent media

42.20.Ee Coherence in random turbulent media, scintillation

42.20.Gg Scattering from haze, fog, dust, etc. *(see also 42.68. Atmospheric optics)*

42.30.−d Optical information, image formation and analysis

42.30.Di Theory

42.30.Fk Aberrations

42.30.Hn Resolution

42.30.Kq Fourier transform optics

42.30.Lr Modulation and optical transfer functions

42.30.Nt Optical storage and retrieval

42.30.Qw Optical communications *(see also 42.80.S. Optical communication devices)*

42.30.Sy Pattern recognition

42.30.Va Image processing and restoration

42.40.−i Holography

42.40.Dp Theory

42.40.Fr Image characteristics

42.40.Ht Photographic and recording problems

42.40.Kw Holographic instrumentation and techniques

42.40.My Applications

42.50.+q Quantum optics

42.52.+x Masers

42.55.−f Lasing processes

42.55.Bi General theory of lasing action

42.55.Dk CO_2 lasers

42.55.Fn Inert gas lasers

42.55.Hq Lasing action in other gas lasers

42.55.Ks Chemical lasers

42.55.Mv Lasing action in liquids and organic dyes

42.55.Px Lasing action in semiconductors

42.55.Rz Lasing action in other solids

42.60.−v Laser systems and laser beam applications

42.60.By Design of specific laser systems

42.60.Da Laser resonators and cavities

42.60.Fc Laser beam modulation

42.60.He Optical problems related to properties and interactions of laser beams

42.60.Kg Optical problems related to applications of laser beams

42.65.−k Nonlinear optics

42.65.Bp General theory

42.65.Cq Stimulated Raman, Brillouin, and Rayleigh scattering; parametric oscillations and harmonic generation

42.65.Gv Photon echoes, self-induced transparency, optical saturation, and related effects

42.65.Jx Beam trapping, self focusing, thermal blooming, and related effects

42.66.−p Vision

42.66.Ct Anatomy and optics of eye

42.66.Ew Physiology of eye: nerve structure and function

42.66.Ja Eye modulation transfer

42.66.Lc Light detection: adaptation and discrimination

42.66.Ne Color detection: adaptation and discrimination

42.66.Qg Scales for light and color detection

42.66.Si Psychophysics of vision, visual perception; binocular vision

42.68.−w Atmospheric optics

42.68.Db Propagation through the atmosphere: attenuation, absorption, and radiation transfer

42.68.Hf Spectral energy distribution, spectral absorption

42.68.Mj Scattering, polarization

42.68.Rp Laser beam propagation

42.68.Sq Image transmission and formation

42.68.Tr Modulation transfer

42.68.Vs Clouds, fog, haze, aerosols; effects of air pollution

42.70.−a Optical materials

42.70.Ce Glass

42.70.Eg Quartz

42.70.Fh Other optical materials

42.70.Gi Light-sensitive materials

42.72.+h Optical sources and standards

For optical measurements and instrumentation, see 07.60

For photometry, radiometry, and colorimetry, see 07.60.D

For polarimetry and ellipsometry, see 07.60.F

For refractometry, reflectometry, see 07.60.H

For interferometers and interferometry, see 07.60.L

For detection of radiation (bolometers, photoelectric cells, infrared and submillimeter wave detection), see 07.62

For spectrometers and spectroscopy, see 07.65

42.78.−b Optical lens and mirror systems

42.78.Cf Lens and mirror design

42.78.Dg Optical system design *(see also 42.30. Image formation)*

42.78.Fi Performance and testing of optical systems *(see also 42.85.F. Optical testing techniques)*

42.78.Hk Coatings

42.78.Mq Eyepieces, projection systems, prism systems

For microscopes, see 07.60.P

For telescopes, see 95.55.C

For photographic, cinematographic, and television cameras, see 07.68

42.80.−f Optical devices, techniques, and applications

42.80.Bi Spatial filters and zone plates

42.80.Cj Spectral and other filters

42.80.Dk Monochromators

42.80.Em Shutters, windows, diaphragms, deflectors

42.80.Fn Gratings, échelles

42.80.Hq Prisms, beam splitters, collimators, and autocollimators

42.80.Ks Optical beam modulators

42.80.Lt Optical waveguides

42.80.Mv Fiber optics

42.80.Nw Schlieren devices

42.80.Px Range finders

42.80.Qy Image detectors, converters, and intensifiers

42.80.Sa Optical communication devices

For laser systems and laser beam applications, see 42.55. and 42.60.; for masers see 42.52.

For holography, see 42.40

For photography, see 07.68

42.82.+n Integrated optics *(see also 42.80.L. Optical waveguides)*

42.85.−x Optical testing and workshop techniques

42.85.Dc Surface grinding, fabrication

42.85.Fe Optical testing techniques

42.90.+m Other topics in optics

50. FLUIDS, PLASMAS, AND ELECTRIC DISCHARGES
(FOR FLUID DYNAMICS, SEE 45; FOR CONDENSED MATTER, SEE 60 AND 70)

51. Kinetic and transport theory of fluids; physical properties of gases

51.10.+y **Kinetic and transport theory**

51.20.+d **Viscosity and diffusion: experimental**

51.30.+i **Thermal properties of gases**

51.40.+p **Acoustical properties of gases; ultrasonic relaxation** *(see also 43. Acoustics; for liquids see 62.60 and 62.80)*

51.50.+v **Electrical phenomena in gases** *(see also 52. Plasma and electric discharges)*

51.60.+a **Magnetic phenomena in gases** *(for liquids, see 75)*

51.70.+f **Optical phenomena in gases** *(for liquids, see 78)*

51.90.+r **Other topics in the physics of fluids**

52. The physics of plasmas and electric discharges *(for solid-state plasma, see 72.30)*

52.20.−j **Elementary processes in plasma**

52.20.Dq Single-particle orbits
52.20.Fs Electron collisions
52.20.Hv Atomic, molecular, heavy-particle collisions

52.25.−b **Plasma basic properties**

52.25.Dg Plasma kinetic equations
52.25.Fi Transport properties
52.25.Gj Fluctuation phenomena
52.25.Kn Thermodynamics of plasmas
52.25.Lp Temperature and density
52.25.Mq Dielectric properties
52.25.Ps Emission, absorption, and scattering of radiation

52.30.+r **Plasma flow; magnetohydrodynamics** *(see also 47.65. Fluid mechanics)*

52.35.−g **Waves, oscillations, and instabilities in plasma**

52.35.Bj Magnetohydrodynamic waves
52.35.Dm Sound waves
52.35.Fp Electrostatic waves and oscillations
52.35.Hr Electromagnetic waves
52.35.Kt Drift waves
52.35.Mw Nonlinear waves and nonlinear interactions
52.35.Py Plasma instabilities
52.35.Ra Plasma turbulence
52.35.Tc Shock waves

52.40.−w **Plasma interactions**

52.40.Db Electromagnetic wave propagation in plasma
52.40.Fd Antennas in plasma; plasma-filled wave guides
52.40.Hf Solid-plasma interactions
52.40.Kh Sheaths
52.40.Mj Beam interactions in plasma

52.50.−b **Plasma production and heating**

52.50.Dg Plasma sources *(see also 52.80. Electric discharges)*
52.50.Gj Plasma heating
52.50.Jm Plasma production and heating by laser beams
52.50.Lp Plasma production and heating by shock wave and wire explosion

52.55.−s **Plasma equilibrium and confinement**

52.55.Dy General theory
52.55.Ez Pinch effect and pinch machines
52.55.Gb Plasma in torus (stellarator, tokamak, MS-torus, Ringleiter, etc.)
52.55.Ke Magnetic traps (e.g., Astron, helitron, mirror, cusp, etc.)
52.55.Mg Nonmagnetic confinement systems (e.g., electrostatic and high frequency confinement, etc.)
52.55.Pi Confinement in fusion reactors *(see also 28.50.R. Fusion reactors)*

52.60.+h **Relativistic plasma**

52.65.+z **Plasma simulation**

52.70.−m **Plasma diagnostic techniques and instrumentation**

52.70.Ds Electric and magnetic measurements
52.70.Gw Radiofrequency and microwave measurements
52.70.Kz Optical measurements
52.70.Nc Particle measurements

52.75.−d **Plasma devices and applications** *(see also 28.50.R. Fusion reactors; for ion sources, see 29.25.C) sources and targets)*

52.75.Di Accelerators and propulsion
52.75.Fk Magnetohydrodynamic generators and thermionic convertors
52.75.Hn Plasma torches
52.75.Kq Plasma switches

52.80.−s **Electric discharges** *(see also 51.50. Electrical phenomena in gases)*

52.80.Dy Conductivity and discharges (low-field and Townsend)
52.80.Hc Glow; corona
52.80.Mg Arcs; sparks
52.80.Pi High-frequency discharge
52.80.Qj Explosions
52.80.Sm Magnetoactive and Penning discharges
52.80.Vp Discharge in vacuum
52.80.Wq Discharge in liquids

52.90.+z **Other topics in plasma physics and electric discharges**

60. CONDENSED MATTER: STRUCTURE, MECHANICAL AND THERMAL PROPERTIES

61. Structure of liquids and solids; crystallography *(see also 68.20. Solid surface structures, 71. Electron states)*

61.10.−i **X-ray determination of structures** *(for specific determinations, see 61.55 to 61.80)*

61.10.Dp Theories of diffraction and scattering
61.10.Fr Experimental techniques

61.12.−q **Neutron determination of structures** *(for specific determinations, see 61.55 to 61.80)*

61.12.Dw Elastic neutron diffraction and scattering
61.12.Fy Inelastic neutron diffraction and scattering

61.14.−x **Electron determination of structures** *(for specific determinations, see 61.55 to 61.80)*

61.14.Dc Theories of diffraction and scattering
61.14.Fe Experimental diffraction and scattering
61.14.Hg Low-energy electron diffraction (LEED) and reflection high-energy electron diffraction (RHEED)

61.16.−d **Other determination of structures** *(for specific determinations, see 61.55 to 61.80)*

61.16.Di Electron microscopy determinations
61.16.Fk Field-ion microscopy determinations
61.16.Hn EPR and NMR determinations

61.20.−p **Classical, semiclassical, and quantum theories of liquid structure** *(for kinetic theory of fluid media, see 51.10; for electronic states, see 71; for liquid helium, see 67)*

61.20.Gy Statistical theories of liquid structure
61.20.Ja Computer simulation of static and dynamic behavior
61.20.Lc Time-dependent properties
61.20.Ne Structure of simple liquids
61.20.Qg Structure of associated liquids

61.25.−f **Studies of specific liquid structures**

61.25.Bi Liquid noble gases
61.25.Em Molecular liquids

61.25.Hq Macromolecular and polymer solutions (solubility, swelling, etc.)

61.25.Ks Molten salts

61.25.Mv Liquid metals

61.30.−v Liquid crystals

61.30.Cz Microstructure theory of liquid crystals

61.30.Eb Experimental determinations of smectic, nematic, cholesteric, and lyotropic structures

61.30.Gd Orientational order of liquid crystals in electric and magnetic fields

61.30.Jf Defects in liquid crystals

61.40.−a Amorphous and polymeric materials

61.40.Df Glasses *(see also 81.20.P, 81.20.Q, and 81.60.F —in materials science)*

61.40.Km Polymers, elastomers, and plastics *(see also 81.20.S, 81.20.T, and 81.60.J —in materials science)*

61.50.−f Crystalline state (including molecular motions in solids) *(for magnetic structure and spin systems, see 75.25)*

61.50.Cj Physics of crystal growth *(for techniques of crystal growth and film deposition, see 81.10 and 81.15; for epitaxy, thin films, see 68.55; for whiskers, see 68.70)*

61.50.Em Crystal symmetry: models, space groups, and crystalline systems and classes

61.50.Jr Crystal morphology and orientation

61.50.Ks Crystallographic aspects of polymorphic and order–disorder transformations

61.50.Lt Crystal binding

61.55.−x Specific structures of elements and alloys

61.55.Dc Nonmetallic elements

61.55.Fe Metallic elements

61.55.Hg Alloys

61.60.+m Specific structures of inorganic compounds

61.65.+d Specific structures of organic compounds

61.70.−r Defects in crystals *(see also 61.80. Radiation damage, 62. Mechanical and acoustical properties, 71.55. Impurities and defect levels, 76.30.M. EPR of color centers and other defects, 78.50. Impurity and defect absorption in solids, 81.40. Treatment of materials)*

61.70.Bv Interstitials and vacancies (excluding color centers)

61.70.Dx Color centers

61.70.Ey Other point defects

61.70.Ga Dislocations: theory

61.70.Jc Etch pits, decoration, transmission electron-microscopy, and other direct observations of dislocations

61.70.Le Slip, creep, internal friction, and other indirect evidence of dislocations

61.70.Ng Grain and twin boundaries

61.70.Ph Stacking faults, stacking fault tetrahedra, and other planar or extended defects

61.70.Rj Crystal impurities: general *(see also 71.55. Electron states)*

61.70.Tm Doping and implantation of impurities

61.70.Wp Impurity concentration, distribution, and gradients *(see also 66.30.J. Diffusion)*

61.70.Yq Interactions between different crystal structure defects

61.80.−x Radiation damage and other irradiation effects *(for techniques of structure determination, see 61.10 to 61.16; for electron and ion impact phenomena, see 79.20)*

61.80.Cb X rays

61.80.Ed γ rays

61.80.Fe Electrons and positrons

61.80.Hg Neutrons

61.80.Jh Ions *(for ion implantation, see 61.70.T)*

61.80.Lj Atoms and molecules

61.80.Mk Channeling, blocking, and energy loss of particles *(see also 29.70.G. Energy loss and range relations)*

61.90.+d Other topics in structure of liquids and solids

62. Mechanical and acoustical properties of condensed matter *(see also 46.30. Mechanics of solids, 61.70. Defects in crystals, 68.30. Surfaces and interfaces, 81. Materials science)*

62.10.+s Mechanical properties of liquids *(for viscosity of liquids, see also 66.20)*

62.20.−x Mechanical properties of solids (related to microscopic structure)

62.20.Dc Elastic constants *(see also 03.40.D. Mathematical theory of elasticity)*

62.20.Fe Deformation and plasticity (including yield, ductility, and superplasticity)

62.20.Hg Creep

62.20.Mk Fatigue, brittleness, fracture, and cracks

62.20.Pn Tribology

62.30.+d Mechanical and elastic waves *(see also 03.40.K. Mathematical problems)*

62.40.+i Anelasticity, internal friction, and mechanical resonances

For thermomechanical effects, see 65.70

For magnetomechanical effects, see 75.80

For piezoelectric effects, see 77.60

For elasto-optical effects, see 78.20.H

62.50.+p High-pressure and shock-wave effects in solids

62.60.+v Acoustical properties of liquids

For sound propagation in liquids and solids, see 43

For lattice dynamics, phonons, see 63

For second sound in quantum fluids, see 67.40.P

62.65.+k Acoustical properties of solids

For magnetoacoustic effects in metals, see 75.80

For acoustoelectric effects, see 72.50

For acousto-optical effects, see 78.20.H

62.80.+f Ultrasonic relaxation *(see also 74.30.G. Ultrasonic attenuation in superconductors, 43.35. Ultrasonics)*

62.90.+k Other topics in mechanical and acoustical properties of condensed matter

63. Lattice dynamics and crystal statistics *(see also 05.50. Lattice theory, 65. Thermal properties, 66.70. Thermal conduction, 68.30. Dynamics of surface and interface vibrations, 78.30. Infrared and Raman spectra)*

63.10.+a General theory

63.20.−e Phonons and vibrations in crystal lattices

63.20.Dj Phonon states and bands, normal modes, and phonon dispersion

63.20.Hp Phonon–phonon interactions

63.20.Kr Phonon–electron interactions

63.20.Mt Phonon–defect interactions

63.20.Pw Localized modes

63.50.+x Vibrational states in disordered systems

63.70.+h Statistical mechanics of lattice vibrations *(see also 65. Thermal properties of condensed matter, and 66.70. Thermal conduction)*

63.75.+z Statistical mechanics of displacive phase-transitions

For order–disorder and statistical mechanics of model systems, see 64.60.C

For crystallographic aspects of polymorphic and order–disorder transformations, see 61.50.K

63.90.+t Other topics in lattice dynamics and crystal statistics

64. Equations of state, phase equilibria, and phase transitions *(see also 82.60. Chemical thermodynamics)*

64.10.+h General theory of equations of state and phase equilibria

64.30.+t Equations of state of specific substances *(see also 65.70. Thermal expansion)*

64.60.−i General studies of phase transitions *(for magnetic, superconducting, and quantum fluid critical phenomena, see 75, 74, and 67 respectively)*

64.60.Cn Order–disorder and statistical mechanics of model systems

64.60.Fr Equilibrium properties near single critical points, critical exponents

64.60.Ht Dynamic critical phenomena

64.60.Kw Multicritical points

64.60.My Metastable phases

64.70.−p Phase equilibria, phase transitions, and critical points of specific substances *(see also 81.30. Phase diagrams and microstructures developed by solidification and solid–solid phase transformations)*

64.70.Dv Solid–liquid transitions

64.70.Ew Transitions in liquid crystals; glass transitions

64.70.Fx Liquid–vapor transitions

64.70.Hz Solid–vapor transitions

64.70.Ja Liquid–liquid transitions

64.70.Kb Solid–solid transitions *(see also 61.50.K. Crystallographic aspects of polymorphic and order-disorder transformations)*

64.75.+g Solubility, segregation, and mixing

64.80.−v Other phase properties of systems

64.80.Eb Stoichiometry and homogeneity

64.80.Gd Microstructure

64.90.+b Other topics in equations of state, phase equilibria, and phase transitions

65. Thermal properties of condensed matter *(see also 05.70. Thermodynamics, 63. Lattice dynamics; for thermodynamic properties of quantum fluids, see 67.40.K; for thermal properties of solid helium, see 67.80.G)*

65.20.+w Heat capacities of liquids

65.40.−f Heat capacities of solids *(for specific heat of superconductors, see 74.30.E.; for specific heat of magnetic systems, see 75.40)*

65.40.Em Lattice and electron heat capacity

65.40.Hq λ and Schottky anomalies

65.50.+m Thermodynamic properties and entropy

65.70.+y Thermal expansion and thermomechanical effects *(see also 64.30. Equations of state)*

For thermal conduction in nonmetallic liquids, see 66.60; for nonmetallic solids, see 66.70

For electronic thermal conduction, see 72.10 and 72.20

For thermal conductivity of superconductors, see 74.30.E

For pyroelectric and electrocaloric effects, see 77.70

65.90.+i Other topics in thermal properties of condensed matter

66. Transport properties of condensed matter (nonelectronic)

66.10.−x Diffusion and ionic conduction in liquids

66.10.Cb Diffusion and thermal diffusion

66.10.Ed Ionic conduction *(see also 82.45. Electrochemistry)*

66.10.Jh Osmosis

66.20.+d Diffusive momentum transport *(for viscosity of liquids, see also 62.10)*

66.30.−h Diffusion in solids

66.30.Dn Theory of diffusion and ionic conduction in solids

66.30.Fq Self-diffusion in metals, semimetals, and alloys

66.30.Hs Self-diffusion and ionic conduction in nonmetals

66.30.Jt Diffusion, migration, and displacement of impurities

66.30.Lw Diffusion, migration, and displacement of other defects

66.30.Ny Chemical interdiffusion

66.60.+a Thermal conduction in nonmetallic liquids *(for thermal conduction in liquid metals, see 72.15.C)*

66.70.+f Nonelectronic thermal conduction and heat-pulse propagation in nonmetallic solids *(for thermal conduction in solid metals, see 72.15.E.; for statistical mechanics of lattice vibrations, see 63.70.)*

66.90.+r Other topics in nonelectronic transport properties

67. Quantum fluids and solids; liquid and solid helium *(see also 05.30. Quantum statistical mechanics)*

67.20.+k Quantum effects on the structure and dynamics of nondegenerate fluids

67.40.−w Boson degeneracy and superfluidity of helium-4

67.40.Bz Phenomenology and two fluid models

67.40.Db Quantum statistical theory; ground state, elementary excitations

67.40.Fd Dynamics of relaxation phenomena

67.40.Hf Hydrodynamics in specific geometries, flow in narrow channels

67.40.Kh Thermodynamic properties

67.40.Mj First sound

67.40.Pm Transport processes, second and other sounds, and thermal counterflow

67.40.Rp Films and weak link transport

67.40.Vs Vortices and turbulence

67.40.Yv Impurities and other defects

67.50.−b Fermi fluids; liquid helium-3

67.50.Dg Normal phase

67.50.Fi Superfluid phase

67.60.−g Mixed systems; liquid helium-3, -4 mixtures

67.60.Dm He I–^{3}He

67.60.Fp He II–^{3}He

67.70.+n Films (including physical adsorption)

67.80.−s Solid helium and related quantum crystals

67.80.Cx Lattice dynamics and sound propagation

67.80.Gb Thermal properties

67.80.Jd Magnetic properties and nuclear magnetic resonance

67.80.Mg Defects, impurities, and diffusion

67.90.+z Other topics in quantum fluids (e.g., neutron-star matter)

68. Surfaces and interfaces; thin films and whiskers *(for impact phenomena, see 79; for crystal growth, see 61.50.C)*

68.10.−m Fluid surfaces and fluid–fluid interfaces

68.10.Cr Surface energy (surface tension, interface tension, angle of contact, etc.)

68.10.Et Interface elasticity, viscosity, and viscoelasticity

68.10.Gw Interface activity, spreading

68.10.Jy Kinetics (evaporation, adsorption, condensation, catalysis, etc.)

68.15.+e Liquid thin films

68.20.+t Solid surface structures

68.25.+j Mechanical and acoustical properties of solid surfaces and interfaces

68.30.+z Dynamics of solid surfaces and interface vibrations

68.40.+e Surface energy of solids; thermodynamic properties *(see also 82.65.D. Thermodynamics of surfaces)*

68.45.−v Solid–fluid interface processes *(see also 82.65.M. Sorption and accommodation coefficients)*

68.45.By Sorption equilibrium

68.45.Da Evaporation and condensation; adsorption and desorption kinetics

68.48.+f Solid–solid interfaces (including bicrystals) *(for grain boundaries, see 61.70.N)*

68.55.+b Thin film growth, structure, and epitaxy *(for techniques of crystal growth and film deposition, see 81.10 and 81.15)*

68.60.+q Physical properties of thin films: nonelectronic

68.70.+w Whiskers and dendrites: growth, structure, and nonelectronic properties

68.90.+g Other topics in the structure and nonelectronic properties of surfaces and thin films

70. CONDENSED MATTER: ELECTRONIC STRUCTURE, ELECTRICAL, MAGNETIC, AND OPTICAL PROPERTIES

71. Electron states *(see also 63. Lattice dynamics, 73. Electronic structure and electrical properties of surfaces, interfaces, and thin films)*

71.10.+x General theories and computational techniques

71.20.+c Electronic density of states determinations (including energy states of liquid semiconductors) *(see also 65.40.E. Electronic heat capacity)*

71.25.−s Nonlocalized single-particle electronic states

71.25.Cx Techniques of band-structure calculation (general theory, applications of group theory, analytic continuation, etc.)

71.25.Hc Measurement of Fermi surface parameters (including dHvA, magnetoacoustic, positron annihilation, and cyclotron resonance studies, etc.)

71.25.Jd Effective mass and g-factors

71.25.Lf Electron energy states in liquid metals

71.25.Mg Electron energy states in amorphous and glassy solids

71.25.Pi Band structure of crystalline metals

71.25.Rk Band structure of crystalline elemental semiconductors

71.25.Tn Band structure of crystalline semiconductor compounds and insulators

71.30.+h Metal–insulator transitions

71.35.+z Excitons and related phenomena (including electron–hole drops)

71.36.+c Polaritons (including photon–phonon and photon–magnon interactions)

71.38.+i Polarons and electron–phonon interactions *(see also 63.20.K. phonon–electron interactions in lattices)*

71.45.−d Collective effects

71.45.Gm Exchange, correlation, dielectric and magnetic functions, plasmons

71.45.Jp Fermi–Thomas models

71.45.Nt Calculations of total electronic binding energy *(see also 61.50.L. Crystal binding)*

71.50.+t Localized single-particle electronic states (excluding impurities)

71.55.−i Impurity and defect levels

71.55.Dp Metals, semimetals, and alloys

71.55.Fr Tetrahedrally bonded nonmetals

71.55.Ht Other nonmetals

71.55.Jv Localization in disordered structures

71.60.+z Positron states *(see also 78.70.B. Positron annihilation)*

71.70.−d Level splitting and interactions *(see also 75.10.—in magnetic phenomena, 75.30.E. Exchange and superexchange interactions, 73.20. Electronic surface states)*

71.70.Ch Crystal and ligand fields

71.70.Ej Spin-orbit coupling, Zeeman, Stark, and strain splitting

71.70.Gm Exchange interactions

71.70.Jp Nuclear states and interactions

71.70.Ms Other bulk localized states and interactions *(for surface states, see 73.20)*

71.90.+q Other topics in electron states

72. Electronic transport in condensed matter *(for surfaces, interfaces, and thin films, see 73)*

72.10.−d Theory of electronic transport; scattering mechanisms

72.10.Bg General formulation of transport theory

72.10.Di Scattering by phonons, magnons, and other nonlocalized excitations *(see also 71.45. Collective effects)*

72.10.Fk Scattering by point defects, dislocations, surfaces, and other imperfections (including Kondo effect)

72.15.−v Electronic conduction in metals and alloys

72.15.Cz Electrical and thermal conduction in amorphous and liquid metals and alloys

72.15.Eb Electrical and thermal conduction in crystalline metals and alloys

72.15.Gd Galvanomagnetic and other magnetotransport effects

72.15.He Thermomagnetic effects

72.15.Jf Thermoelectric effects

72.15.Lh Relaxation times and mean free paths

72.15.Nj Collective modes (e.g., in one-dimensional conductors)

72.15.Qm Scattering mechanisms and Kondo effect *(see also 75.20.H. Local moments in dilute alloys)*

72.20.−i Conductivity phenomena in semiconductors and insulators *(for nonelectronic conduction, see 66.70)*

72.20.Dp Scattering mechanisms

72.20.Fr Low-field transport and mobility; piezoresistance

72.20.Ht High-field and nonlinear effects

72.20.Jv Charge carriers: generation, recombination, lifetime, and trapping

72.20.My Galvanomagnetic and other magnetotransport effects

72.20.Nz Thermomagnetic effects

72.20.Pa Thermoelectric effects

72.30.+q High-frequency effects; plasma effects

72.40.+w Photoconduction and photovoltaic effects; photodielectric effects

72.50.+b Acoustoelectric effects

72.55.+s Magnetoacoustic effects

72.60.+g Mixed conductivity and conductivity transitions

72.70.+m Noise processes and phenomena

72.80.−r Conductivity of specific semiconductors and insulators

72.80.Cw Elemental semiconductors

72.80.Ey III-V and II-VI semiconductors

72.80.Ga Transition-metal compounds

72.80.Jc Other crystalline inorganic semiconductors

72.80.Le Organic semiconductors

72.80.Ng Amorphous and glassy semiconductors

72.80.Ph Liquid semiconductors

72.90.+y Other topics in electronic transport in condensed matter

73. Electronic structure and electrical properties of surfaces, interfaces, and thin films

73.20.−r Electronic surface states *(for emission and impact phenomena, see 79)*

73.20.Cw Ideal surfaces

73.20.Hb Impurity and imperfection levels

73.25.+i Surface conductivity

73.30.+y Surface double layers, Schottky barriers, and work functions

73.40.−c Interfaces

73.40.Bf Static electrification

73.40.Cg Contact resistance, contact potential

73.40.Ei Rectification

73.40.Gk Tunneling: general *(see also 74.50—in superconductors)*

73.40.Jn Metal-to-metal contacts

73.40.Lq Semiconductor-to-semiconductor contacts, *p–n* junctions, and

73.40.Mr Semiconductor–electrolytic contacts

73.40.Ns Metal–nonmetal contacts

73.40.Qv Metal–insulator–semiconductor structures (including semiconductor-to-insulator)

73.40.Rw Metal–insulator–metal structures

73.40.Sx Metal–semiconductor–metal structures

73.40.Ty Semiconductor–insulator–semiconductor structures

73.40.Vz Semiconductor–metal–semiconductor structures

73.60.−n Electronic properties of thin films

73.60.Dt Metallic thin films

73.60.Fw Semiconductor films

73.60.Hy Insulating thin films

73.60.Ka Superconducting films

73.90.+f Other topics in electrical properties of surfaces, interfaces, and thin films

74. Superconductivity

74.10.+v Occurrence, critical temperature

74.20.−z Theory

74.20.De Phenomenological and two-fluid theories

74.20.Fg BCS theory; applications

74.30.−e General properties

74.30.Ci Magnetization curves, Meissner effect, penetration depth

74.30.Ek Thermodynamic properties; thermal conductivity

74.30.Gn Response to electromagnetic fields, nuclear magnetic resonance, ultrasonic attenuation

74.40.+k **Fluctuations and critical effects**

74.50.+r **Tunneling phenomena, Josephson effect, and proximity effects**

74.55.+h **Type-I superconductivity**

74.60.−w **Type-II superconductivity**

74.60.Ec Mixed state, H_{c2}, surface sheath

74.60.Ge Flux pinning; fluxon–defect interactions

74.60.Jg Critical currents

74.70.−b **Superconducting materials**

74.70.Dg Material effects on T_c, κ, critical currents

74.70.Gj Type-I superconductors (nontransition metals and their alloys and compounds)

74.70.Lp Type-II superconductors (transition metals and their alloys and compounds)

74.70.Nr Dirty superconductors

74.70.Ps Materials for high-field applications

74.70.Rv Other superconducting materials

74.90.+n **Other topics in superconductivity**

75. Magnetic properties and materials

75.10.−b **General theory and models of magnetic ordering** *(see also 05.50. Ising problems, 71.25. Nonlocalized single-particle electronic states, 71.70. Level splitting and interactions)*

75.10.Dg Crystal-field theory and spin Hamiltonians

75.10.Hk Ising and other classical spin models

75.10.Jm Heisenberg and other quantized localized spin models

75.10.Lp Band and itinerant models

75.20.−g **Diamagnetism and paramagnetism**

75.20.Ck Nonmetals

75.20.En Metals and alloys

75.20.Hr Local moment in dilute alloys; Kondo effect *(see also 72.15.Q. Electronic conduction)*

75.25.+z **Spin arrangements in magnetically ordered materials (neutron studies, etc.)**

75.30.−m **Magnetically ordered materials, other intrinsic properties** *(for critical point effects, see 75.40)*

75.30.Cr Saturation moments and magnetic susceptibility

75.30.Ds Spin waves *(see also 76.50. Spin-wave resonance)*

75.30.Et Exchange and superexchange interactions *(see also 71.70. Level splitting and interactions)*

75.30.Gw Anisotropy

75.30.Hx Magnetic impurity interactions

75.30.Kz Magnetic phase boundaries (including magnetic transitions, metamagnetism, etc.)

75.30.Sg Magnetocaloric effect

75.40.+t **Critical-point effects, specific heats, short-range order** *(see also 65.40. Heat capacities)*

75.40.Bw General theory

75.40.Dy Ising and other classical spin models

75.40.Fa Heisenberg and other quantized spin models

75.50.−y **Studies of specific magnetic materials**

75.50.Bb Ferromagnetism of Fe and its alloys

75.50.Cc Ferromagnetism of other metals

75.50.Dd Ferromagnetism of nonmetals

75.50.Ee Antiferromagnetics

75.50.Gg Ferrimagnetics

75.50.Kj Amorphous magnetic materials

75.50.Mm Magnetic liquids

75.60.−d **Domain effects, magnetization curves, and hysteresis**

75.60.Ch Domain walls and domain structure *(for magnetic bubbles, see 75.70.K)*

75.60.Ej Magnetization curves, hysteresis, Barkhausen and related effects

75.60.Gm High coercivity materials

75.60.Jp Fine-particle systems

75.60.Lr Magnetic aftereffects

75.60.Nt Magnetic annealing and temperature-hysteresis effects

75.70.−i **Magnetic films and plates**

75.70.Dp Properties in uniform state

75.70.Kw Domain structure (magnetic bubbles)

75.80.+q **Magnetomechanical and magnetoelectric effects, magnetostriction**

For galvanomagnetic effects, see 72.15.G and 72.20.M

For magneto-optical effects, see 78.20.L

75.90.+w **Other topics in magnetic properties and materials**

76. Magnetic resonances and relaxation in condensed matter; Mössbauer effect

76.20.+q **General theory of resonances and relaxation**

For measurement techniques, see 07.58

76.30.−v **Electron paramagnetic resonance and relaxation**

76.30.Da Ions and impurities: general

76.30.Fc Iron group (3*d*) ions and impurities (Ti–Cu)

76.30.He Platinum and palladium group (4*d* and 5*d*) ions and impurities (Zr–Ag and Hf–Au)

76.30.Kg Rare-earth ions and impurities

76.30.Mi Color centers and other defects

76.30.Pk Conduction electrons

76.30.Rn Free radicals

76.40.+b **Diamagnetic and cyclotron resonances**

76.50.+g **Ferromagnetic, antiferromagnetic, and ferrimagnetic resonances; spin-wave resonance** *(see also 75.30.D. Spin waves)*

76.60.−k **Nuclear magnetic resonance and relaxation**

76.60.Cq Chemical and Knight shifts

76.60.Es Relaxation effects

76.60.Gv Quadrupole resonance

76.60.Jx Effects of internal magnetic fields

76.60.Lz Spin echoes

76.70.−r **Magnetic double resonances and cross effects**

76.70.Dx Electron-nuclear double resonance (ENDOR)

76.70.Ey Dynamical nuclear polarization

76.70.Fz Double nuclear magnetic resonance (DNMR)

76.70.Hb Optical double magnetic resonance (ODMR)

76.70.Kd Electron double resonance (ELDOR)

76.80.+y **Mössbauer effect; other γ-ray spectroscopy**

76.90.+d **Other topics in magnetic resonances and relaxation**

77. Dielectric properties and materials *(for conductivity phenomena, see 72.20 and 72.80)*

77.20.+y **Permittivity**

77.30.+d **Polarization and depolarization effects**

77.40.+i **Dielectric loss and relaxation**

77.50.+p **Dielectric breakdown and space-charge effects**

77.55.+f **Dielectric thin films**

77.60.+v **Piezoelectricity and electrostriction** *(for piezo-optical effects, see 78.20.H)*

77.70.+a **Pyroelectric and electrocaloric effects**

77.80.−e **Ferroelectricity and antiferroelectricity**

77.80.Bh Transitions and Curie point

77.80.Dj Domain structure and effects; hysteresis

77.85.+x **Electrical resonances**

77.90.+k **Other topics in dielectric properties and materials**

78. Optical properties and condensed-matter spectroscopy and other interactions of matter with particles and radiation *(for phonon spectra, see 63)*

78.20.−e **Optical properties and materials** *(see also 42.65. Nonlinear optics; for masers and lasers, see 42.52, and 42.55 and 42.60, respectively)*

78.20.Bh General theory (for pure homogeneous materials)

78.20.Dj Optical constants and parameters

78.20.Ek Optical rotatory power

78.20.Fm Birefringence (including stress birefringence, flow birefringence, etc.)

78.20.Hp Piezo-, elasto-, and acousto-optical effects

78.20.Jq Electro-optical effects

78.20.Ls Magneto-optical effects

78.20.Nv Thermo-optical effects

78.30.−j **Infrared and Raman spectra and scattering**

78.30.Cp Infrared and Raman spectra in liquids

78.30.Er Infrared and Raman spectra in metals

78.30.Gt	Infrared and Raman spectra in inorganic crystals
78.30.Jw	Infrared and Raman spectra in organic crystals

78.35.+c Brillouin and Rayleigh scattering

78.40.−q Visible and ultraviolet spectra

78.40.Dw	Liquids
78.40.Fy	Tetrahedrally bonded nonmetals
78.40.Ha	Other nonmetals
78.40.Kc	Metals, semimetals, and alloys

78.45.+h Stimulated emission *(see also 42.65.D —in nonlinear optics)*

78.50.−w Impurity and defect absorption in solids

78.50.Ec	Insulators
78.50.Ge	Semiconductors
78.50.Jg	Metals, semimetals, and alloys

78.55.−m Photoluminescence

78.55.Bq	Liquids
78.55.Ds	Tetrahedrally bonded nonmetals
78.55.Fv	Alkali halides
78.55.Hx	Other inorganic materials
78.55.Kz	Organic materials

78.60.−b Other luminescence and radiative recombination

78.60.Fi	Electroluminescence
78.60.Hk	Cathodoluminescence, ionoluminescence
78.60.Kn	Thermoluminescence
78.60.Mq	Sonoluminescence, triboluminescence
78.60.Ps	Chemiluminescence

For photoconduction and photovoltaic effects, see 72.40

78.65.−s Optical properties of thin films

78.65.Ez	Metals
78.65.Jd	Nonmetals

78.70.−g Other interactions of matter with particles and radiation

78.70.Bj	Positron annihilation *(see also 71.60. Positron states)*
78.70.Ck	X-ray scattering
78.70.Dm	X-ray absorption and absorption edges
78.70.En	X-ray emission threshold and fluorescence
78.70.Gq	Microwave and radiofrequency (excluding resonances)

78.90.+t Other topics in optical properties of condensed matter and other interactions of matter with particles and radiation

79. Electron and ion emission by liquids and solids; impact phenomena

79.20.−m Impact phenomena, including electron spectra and sputtering

79.20.Ds	Laser-light impact phenomena
79.20.Fv	Electron impact: Auger emission
79.20.Hx	Electron impact: secondary emission
79.20.Kz	Other electron impact phenomena
79.20.Nc	Atom, molecule, and ion impact
79.20.Rf	Atomic and molecular beam interactions

79.40.+z Thermionic emission

79.60.−i Photoemission and photoelectron spectra

79.60.Cn	Clean metals
79.60.Eq	Semiconductors and insulators
79.60.Gs	Composite surfaces

79.70.+q Field emission and field ionization

79.75.+g Exoelectron emission

79.80.+w Resonance tunneling

79.90.+b Other topics in emission and impact phenomena in condensed matter

80. CROSS-DISCIPLINARY PHYSICS AND RELATED AREAS OF SCIENCE AND TECHNOLOGY

81. Materials science

81.10.−h Methods of crystal growth and purification *(for physics of crystal growth, see 61.50.C)*

81.10.Bk	Growth from vapor
81.10.Dn	Growth from solutions
81.10.Fq	Growth from melts
81.10.Hs	Zone melting and refining
81.10.Jt	Growth from solid phases (including multiphase diffusion and recrystallization)

81.15.−z Methods of thin film deposition *(for epitaxy, see 68.55)*

81.15.Cd	Deposition by cathodic sputtering
81.15.Ef	Vacuum deposition
81.15.Gh	Chemical vapor deposition
81.15.Jj	Ion plating and other vapor deposition
81.15.Lm	Deposition from liquid phases (melts and solutions)

81.20.−n Other methods of preparation of materials

81.20.Cs	Vacuum methods
81.20.Ev	Powder techniques, compaction and sintering
81.20.Gx	Specific metals and alloys (compaçts, pseudoalloys)
81.20.Jz	Dispersion-, fiber-, and platelet-reinforced metal-based composites
81.20.Lb	Ceramics and refractories
81.20.Nd	Cermets, ceramic and refractory composites
81.20.Pe	Glasses
81.20.Qf	Glass-based composites, vitroceramics
81.20.Sh	Polymers
81.20.Ti	Reinforced polymers and polymer-based composites

81.30.−t Phase diagrams and microstructures developed by solidification and solid–solid phase transformations *(see also 61. Structure of liquids and solids and 64.70. Phase equilibria, phase transitions, and critical points of specific substances)*

81.30.Bx	Phase diagrams of metals and alloys
81.30.Dz	Phase diagrams of other materials
81.30.Fb	Solidification
81.30.Hd	Constant-composition solid–solid phase transformations: polymorphic, massive, order–disorder
81.30.Kf	Martensitic transformations
81.30.Mh	Precipitation

81.40.−z Treatment of materials and its effects on microstructure and properties

81.40.Cd	Solid solution, precipitation, and dispersion hardening
81.40.Ef	Cold working, work hardening; annealing, recovery, and recrystallization; textures
81.40.Gh	Other heat and thermomechanical treatments
81.40.Jj	Elasticity and anelasticity
81.40.Lm	Deformation, plasticity, and creep
81.40.Np	Fatigue, embrittlement, and fracture
81.40.Pq	Friction, lubrication, and wear
81.40.Rs	Electrical and magnetic properties (in relation with treatment conditions)
81.40.Tv	Optical properties (in relation with treatment conditions)

81.60.−j Corrosion, oxidation, and surface treatments

81.60.Bn	Metals and alloys
81.60.Dq	Ceramics and refractories
81.60.Fs	Glasses
81.60.Hv	Composites
81.60.Jw	Polymers

81.70.+r Materials testing

81.90.+c Other topics in materials science and metallurgy

82. Physical chemistry

82.20.−w Chemical kinetics

82.20.Db	Statistical theories, including transition state
82.20.Fd	Stochastic and trajectory models, other theories and models
82.20.Hf	Mechanisms and product distribution
82.20.Kh	Potential energy surfaces for chemical reactions *(see also 31.70.F. —in atomic and molecular physics; 34.20.B. General potential functions, 34.50.L. Chemical reactions, as studied by atomic and molecular beams)*
82.20.Mj	Nonequilibrium kinetics
82.20.Pm	Measurements of rate constants, reaction cross sections, and activation energies
82.20.Rp	Energy distribution and transfer; relaxation *(see also 31.70.H. Time-dependent phenomena —in atomic and molecular physics*
82.20.Tr	Kinetic and isotope effects
82.20.Wt	Computational modeling

82.30.−b Specific chemical reactions; reaction mechanisms

82.30.Cf Atom and radical reactions (with themselves or with molecules)

82.30.Eh Molecule–molecule reactions

82.30.Fi Ion–molecule, ion–ion, and charge-transfer reactions *(see also 34.70. Charge transfer)*

82.30.Hk Chemical exchanges (substitution, atom transfer, abstraction, disproportionation, and group exchange)

82.30.Lp Decomposition reactions (pyrolysis, dissociation, and group ejection)

82.30.Nr Association, addition, and insertion

82.30.Qt Isomerization and rearrangement

82.30.Sw Chain reactions

82.30.Vy Homogeneous catalysis *(see also 82.65.J. Heterogeneous catalysis at surfaces)*

82.35.+t Polymer reactions and polymerization

82.40.−g Chemical kinetics and reactions: special regimes

82.40.Dm Atomic and molecular beam reactions *(see also 34.50.L. Chemical reactions as studied by atomic and molecular beams)*

82.40.Fp Shock waves

82.40.Js Fast and ultrafast reactions

82.40.Mw Pulse techniques

82.40.Py Flames, combustion, and explosions

82.40.Ra Flowing afterglow

82.40.Tc Chemiluminescence and chemical laser kinetics *(see also 42.55. Lasing processes)*

82.40.Wc Chemistry of the upper atmosphere *(see also 94.10.F. Atmospheric composition, chemical reactions and processes)*

82.45.+z Electrochemistry and electrophoresis *(see also 66.10.E. Ionic conduction in liquids; for electro-osmosis, see 82.65.F)*

82.50.−m Photochemistry and radiation chemistry *(see also 33.50. Fluorescence, phosphorescence, radiationless transitions)*

82.50.Cr Quantum yields

82.50.Et Photodissociation and photoionization, as studied by fluorescence and radiationless transitions

82.50.Jy Energy deposition

82.50.La Ion-pair yields

82.50.Rf *G* values

82.55.−d Radiochemistry

82.55.Di Hot atom reactions

82.55.Gm Positronium chemistry

82.55.Kq Tracer reactions

82.60.−s Chemical thermodynamics *(see also 05.70. Thermodynamics)*

82.60.Cx Enthalpies of combustion, reaction, and formation

82.60.Fa Heat capacity and heats of phase transitions

82.60.Hc Chemical equilibria and equilibrium constants

82.60.Lf Thermodynamics of solutions

82.60.Nh Nucleation

82.65.−i Surface processes *(see also 68.40. Surface energy of solids; thermodynamic properties)*

82.65.Dp Thermodynamics of surfaces

82.65.Fr Film and membrane processes; ion exchange, dialysis, osmosis, electro-osmosis

82.65.Jv Heterogeneous catalysis at surfaces and other surface reactions *(see also 82.30.V. Homogeneous catalysis)*

82.65.My Sorption and accommodation coefficients *(see also 68.45. Solid–fluid interface processes)*

82.65.Nz Other gas–surface interactions

82.70.−y Disperse systems

82.70.Dd Colloids

82.70.Gg Gels and sols

82.70.Kj Emulsions and suspensions

82.70.Rr Aerosols and foams

82.80.−d Chemical analysis and related physical methods of analysis

82.80.Bg Chromatography (including paper, column, thin film, vapour phase, and ion exchange chromatography)

82.80.Di Electromagnetic radiation spectrometry (including optical, x-ray, and magnetic resonance methods)

82.80.Fk Electrochemical methods

82.80.Jp Radiochemical activation analysis methods

82.80.Ms Mass spectrometry *(see also 07.75. Mass spectrometers and mass spectrometry techniques)*

82.80.Pv Electron spectroscopy for chemical analysis (photoelectron, Auger spectrometry, etc.)

82.80.Sy Methods using colligative properties

82.90.+j Other topics in physical chemistry

84. Electromagnetic technology

84.20.−k Circuit theory *(for filters, see 84.30.V)*

84.20.Cq Network topology

84.20.Es General analysis and synthesis methods

84.20.Hw Computer-aided circuit analysis and design

84.20.Ky Lumped linear networks

84.20.Ma Distributed linear networks *(for transmission-line theory, see 84.40.M; for waveguide theory, see 84.40.S)*

84.20.Pc Nonlinear network analysis and design

84.20.Re Time-varying and switched networks

84.30.−r Electronic circuits

84.30.Dx Parametric microwave circuits

84.30.Fz Solid-state microwave circuits

84.30.Jc Power electronics, supply, and supervisory circuits

84.30.Le Amplifiers

84.30.Ng Oscillators

84.30.Qi Modulators and demodulators; discriminators and mixers

84.30.Sk Pulse and digital circuits *(for pulse generators, see 84.30.N)*

84.30.Vn Filters and other networks

84.30.Wp Special-purpose electronic circuits *(see also 29.60. Counting circuits)*

84.40.−x Antennas, transmission lines, and propagation

84.40.Cb Radio-wave propagation effects

84.40.Ed Optical propagation effects

84.40.Gf Antenna theory

84.40.Jh Antennas

84.40.Ki Antenna accessories

84.40.Mk Transmission-line theory

84.40.Nm Transmission lines and cables

84.40.Pn Transmission-line accessories

84.40.Qp Transmission-line components

84.40.Sr Waveguide theory

84.40.Ts Waveguides (including strip lines)

84.40.Vt Optical waveguides

84.40.Wv Waveguide components

84.60.−h Direct energy conversion and energy storage

84.60.Dn Electrochemical conversion and storage, general

84.60.Ep Primary cells

84.60.Fq Secondary cells

84.60.Gr Fuel cells

84.60.Jt Solar cells and arrays *(for other photoelectric devices, see 85.60)*

84.60.Lw Magnetohydrodynamic conversion

84.60.Ny Thermionic conversion

84.60.Rb Other direct energy conversion, including electrogasdynamic, thermoelectric conversion, etc. *(for thermocouples, see 85.80.F)*

84.60.Td Other energy storage including capacitor banks *(for capacitors, see 85.50.N)*

84.70.+p High-current and high-voltage technology

For particle beams and particle optics, see 41.80.

84.90.+a Other topics in electromagnetic technology

85. Electrical and magnetic devices

85.10.−n Electron tubes

85.10.Dt Electron tube technology

85.10.Fw Vacuum tubes

85.10.Hy Traveling-wave tubes

85.10.Ka Other microwave tubes

85.10.Mc Cathode-ray and storage tubes

85.10.Pe Phototubes

85.10.Rg Gas-discharge tubes

85.20.−t Conductors, inductors, and switches

85.20.Cy Conductors

85.20.Ea Resistors (including thermistors, varistors, and photoresistors)

85.20.Gc Inductors and coils

85.20.Je Signal and power transformers

85.20.Lg Printed circuits

85.20.Ni Wiring

85.20.Qk Connectors

85.20.Sn Electrical contacts

85.20.Tp Relays

85.20.Vq Switches

85.20.Wr Fuses

85.25.+k Superconducting devices; superconducting magnets *(see also 74.50. Superconducting materials and devices)*

85.30.−z Semiconductor devices *(for photodiodes and phototransistors, see 85.60.D)*

85.30.De Semiconductor-device characterization and modeling
85.30.Fg Bulk semiconductor and conductivity oscillation devices
85.30.Hi Surface barrier, boundary, and point contact devices
85.30.Kk Classical junction diodes
85.30.Mn Junction breakdown and tunneling devices
85.30.Pq Bipolar transistors
85.30.Rs Thyristors
85.30.Tv Field effect devices

85.40.−e Integrated electronics

85.40.Ci Integrated microcircuits, general
85.40.Dj Thick-film integrated circuits
85.40.Ek Thin-film integrated circuits
85.40.Fm Semiconductor multichip integrated circuits
85.40.Gn Semiconductor monolithic integrated circuits
85.40.Kr Hybrid integrated circuits
85.40.Mt Microassembly, general
85.40.Nv Discrete component microassembly
85.40.Pw Semiconductor multichip microassembly

85.50.−j Dielectric devices

85.50.Dq Inorganic insulators
85.50.Fs Organic and plastic insulators
85.50.Hv Insulating coatings
85.50.Ly Ferroelectric and piezoelectric devices
85.50.Na Capacitors *(for energy storage, see 84.60.T)*

85.60.−q Photoelectric and optoelectronic devices and systems

85.60.Dw Photoelectric devices (including photodiodes and phototransistors)
85.60.Gz Photodetectors and infrared detectors *(for phototubes, see 85.10.P; see also 29.40. Radiation detection)*
85.60.Jb Light-emitting devices *(for cathode-ray tubes, see 85.10.M)*
85.60.Me Other optoelectronic devices *(for photoresistors, see 85.20.E)*
85.60.Pg Display systems *(see also 06.70.H. Display, recording instruments)*

85.70.−w Magnetic devices

85.70.Ca Magnetic cores
85.70.Ec Magnetostrictive devices
85.70.Ge Ferrite and garnet devices
85.70.Kh Magnetic thin-film devices
85.70.Nk Magnets
85.70.Qn Magnetic device circuits
85.70.Sq Magneto-optical devices

85.80.−b Electrochemical, thermoelectromagnetic, and other devices *(for acoustoelectric devices, see 43.85)*

85.80.Dg Electrochemical devices
85.80.Fi Thermoelectric devices
85.80.Jm Magnetoelectric devices
85.80.Lp Magnetothermal devices

85.90.+h Other topics in electrical and magnetic devices

87. Biophysics, medical physics, and biomedical engineering

87.10.+e General, theoretical, and mathematical biophysics (including logic of biosystems, quantum biology, and relevant aspects of thermodynamics, information theory, cybernetics, and bionics)

87.15.−v Molecular biophysics

87.15.By Structure, configuration, conformation, and active sites at the molecular level
87.15.Da Physical chemistry of solutions; condensed states
87.15.He Molecular dynamics, molecular probes, molecular pattern recognition
87.15.Kg Molecular interactions, charge transfer complexes
87.15.Mi Interactions with radiations at the molecular level; luminescence
87.15.Pk Model reactions

87.18.+f Biothermics

87.20.−i Membrane biophysics

87.20.Cn General theory of interfaces (including practical models)
87.20.Eq Natural and artificial membranes (including immobilized enzymes)

87.25.−a Cellular biophysics

87.25.Bd Bioenergetics (including photosynthesis)
87.25.Df Biological transport; cellular and subcellular transmembrane physics
87.25.Fh Physics of subcellular structures

87.30.−p Biophysics of neurophysiological processes (excluding perception processes and speech)

87.30.Ct Electrical activity for excitable and nonexcitable biosystems
87.30.Ew External and internal data communications, nerve conduction and synaptic transmission (including neuromuscular transmission and muscular contraction)
87.30.Gy Memory storage and memorization (biophysical and biochemical processes)

For vision, see 42.66

87.34.+d Audition

87.36.+j Speech

87.38.+r Mechano- and chemoceptions (including biosonic generation, detection, and guidance)

87.40.+w Biomagnetism (including magnetocardiography)

87.45.−k Biomechanics, biorheology, biological fluid dynamics

87.45.Bp Mechanical properties of tissues and organs
87.45.Dr Physics of body movements
87.45.Ft Rheology of body fluids
87.45.Hw Haemodynamics, pneumodynamics

87.50.−a Biological effects of radiations

87.50.Bd Interactions of biosystems with radiations
87.50.Cc Bioacoustics (sonic and ultrasonic effects on living matter)
87.50.Eg Bio-optics (effects of microwaves, light, laser, and other electromagnetic waves)
87.50.Gi Ionizing radiations (uv, x-ray, γ-ray, and particle radiation effects)

87.60.−f Medical and biomedical uses of fields, radiations, and radioactivity *(see also 28.80. Nuclear radiation technology, including shielding)*

87.60.Bi Sonic and ultrasonic radiation
87.60.Dk Electric and magnetic fields (d.c. and pulsed)
87.60.Gp Laser beams, microwaves, and other electromagnetic waves
87.60.Jr Corpuscular radiation and radioisotopes
87.60.Lt Preparation of radioactive materials for medical and biomedical uses
87.60.Mv Radiation dosimetry
87.60.Px Radiation protecion
87.60.Rz Radioactive pollution

87.65.+y Aerospace biophysics and medical physics (effects of accelerations, weightlessness and environment) *(see also 94.80. Aerospace facilities and techniques)*

87.70.−k Biomedical engineering

87.70.Cq Technobiology
87.70.Es Diagnostic methods and instrumentation
87.70.Gv Patient care and treatment
87.70.Jx Prosthetics and other practical applications

87.80.+s Biophysical instrumentation and techniques

87.90.+y Other topics in biophysics, medical physics, and biomedical engineering

89. Other areas of research of general interest to physicists

89.20.+a Industrial and technological research and development

89.30.+f Energy resources

89.40.+k Transportation

89.50.+r Urban planning and development

89.60.+x Environmental and ecological studies

89.70.+c Information science

89.80.+h Computer science and technology

89.90.+n Other areas of general interest to physicists

90. GEOPHYSICS, ASTRONOMY, AND ASTROPHYSICS

91. Solid Earth geophysics

91.10.−v Geodesy and gravity

91.10.By Mathematical geodesy; general theory
91.10.Da Cartography
91.10.Jf Topography; geometric observations
91.10.Lh Photogrammetry
91.10.Nj Rotational variations; polar wobble
91.10.Qm Harmonics of the gravity potential field

For relations of gravity observations to tectonics and isostasy, see 91.45.S

91.10.Tq Earth tides

91.25.−r Geomagnetism and paleomagnetism; geoelectricity

91.25.Cw Origins and models of the magnetic field; dynamo theories
91.25.Ey Interactions between exterior sources and interior properties (magnetotelluric effects)
91.25.Ga Spatial variations: all harmonics and anomalies
91.25.Jc Spatial variations attributed to sea floor spreading
91.25.Lc Time variations, diurnal to secular
91.25.Ng Paleomagnetism
91.25.Qi Earth's electricity; electromagnetic induction and conductivity

91.30.−f Seismology

91.30.Bi Seismic sources (mechanisms, magnitude, moment frequency spectrum)
91.30.Dk Seismicity, space and time distribution (including strong motion and shock waves)
91.30.Fn Surface and body waves
91.30.Ks Free oscillations (periods less than 12 hours)
91.30.Mv Strong motions and shock waves
91.30.Nw Tsunamis *(see also 92.10.D. and 92.10.F. for dynamics of the ocean)*
91.30.Px Phenomena related to earthquake prediction
91.30.Rz Explosion seismology

91.35.−x Earth's interior structure and properties

91.35.Cb Models of interior structure
91.35.Dc Heat flow; geothermy
91.35.Ed Structure of the Earth's interior below the upper mantle
91.35.Gf Structure of the crust and upper mantle
91.35.Lj Composition of Earth's interior
91.35.Nm Geochronology

91.40.+m Volcanology

91.45.−c Physics of plate tectonics

91.45.Dh Plate tectonics
91.45.Fj Convection currents
91.45.Pt Slow vertical crustal movements (including isostasy and postglacial phenomena)
91.45.Sx Relations of gravity observations to tectonics and isostasy

91.50.−r Marine geology and geophysics

91.50.Cw Beach, coastal, and shelf processes
91.50.Ey Ocean bottom processes
91.50.Ga Bathymetry and noncoastal underwater morphology
91.50.Jc Turbidity currents, sedimentation

91.60.−x Physical properties of rocks and minerals

91.60.Ba Elasticity, fracture, and flow
91.60.Fe Equations of state
91.60.Hg Phase changes
91.60.Ki Thermal properties
91.60.Pn Magnetic and electric properties

91.65.+p Geophysical aspects of geology, mineralogy, and petrology

91.90.+p Other topics in solid earth geophysics

92. Hydrospheric and atmospheric geophysics

92.10.−c Physics of the oceans

92.10.Bf Physical properties of seawater
92.10.Dh Dynamics of the deep ocean
92.10.Fj Dynamics of the upper ocean
92.10.Hm Surface waves, tides, and sea level
92.10.Jn Seiches
92.10.Kp Sea-air energy exchange processes
92.10.Lq Turbulence and diffusion
92.10.Mr Thermohaline structure and circulation
92.10.Pt Underwater light and radiation energy
92.10.Rw Sea ice
92.10.Sx Coastal and estuarine oceanography
92.10.Vz Underwater sound

For marine geology and geophysics, see 91.50

92.20.−h Interdisciplinary aspects of oceanography

92.20.Cm Chemistry of the ocean
92.20.Gr Ocean energy extraction
92.20.Jt Biological aspects of oceanography
92.20.Ny Submarine pollution

92.40.−t Hydrology and glaciology

92.40.Cy Modeling; general theory
92.40.Ea Precipitation
92.40.Fb Rivers, runoff, and streamflow
92.40.Gc Erosion and sedimentation
92.40.Je Evaporation
92.40.Kf Groundwater
92.40.Lg Soil moisture
92.40.Ni Limnology
92.40.Qk Water quality and water resources
92.40.Rm Snow
92.40.Sn Ice
92.40.Vq Glaciers

92.60.−e Meteorology

92.60.Bh General circulation
92.60.Dj Gravity waves, tides, and compressional waves
92.60.Ek Convection, turbulence, and diffusion
92.60.Fm Boundary layer structure and processes
92.60.Gn Winds and their effects
92.60.Hp Chemical composition and chemical interactions
92.60.Jq Water in the atmosphere (humidity, clouds, evaporation, precipitation)
92.60.Ls Ionic interactions and processes
92.60.Mt Particles and aerosols *(see also 94.20 Physics of the ionosphere)*
92.60.Nv Cloud physics
92.60.Pw Atmospheric electricity
92.60.Qx Storms
92.60.Ry Climatology
92.60.Sz Air quality and air pollution
92.60.Ta Interaction of atmosphere with electromagnetic waves; propagation
92.60.Vb Solar radiation
92.60.Wc Weather analysis and prediction
92.60.Yd Meteorological applications

For atmospheric optics, see 42.68

92.90.+x Other topics in hydrospheric and atmospheric geophysics

93. Geophysical observations, instrumentation, and techniques

93.30.−w Information related to geographical regions

93.30.Bz Africa
93.30.Ca Antarctica
93.30.Db Asia
93.30.Fd Australia
93.30.Ge Europe
93.30.Hf North America
93.30.Jg South America
93.30.Kh Large islands (e. g., Greenland)
93.30.Li Arctic Ocean
93.30.Mj Atlantic Ocean
93.30.Nk Indian Ocean
93.30.Pm Pacific Ocean
93.30.Qn Southern Ocean
93.30.Rp Regional seas
93.30.Sq Polar regions
93.30.Tr Temperate regions
93.30.Vs Tropical regions

93.55.+z International organizations, national and international programs

93.65.+e Data acquisition and storage

93.85.+q Instrumentation and techniques for geophysical research

94. Aeronomy and space physics

94.10.−s Physics of the neutral atmosphere ***(for atmospheres of the planets, see 96.30)***

94.10.Bw General properties of the high atmosphere
94.10.Dy Atmospheric structure, pressure, density, and temperature (stratosphere, mesosphere, thermosphere, exosphere)

94.10.Fa Atmospheric composition (atomic or molecular), chemical reactions and processes *(see also 82.40.W. Chemistry of the upper atmosphere)*
94.10.Gb Absorption and scattering of radiation
94.10.Hc Atmospheric albedo to particles or waves
94.10.Jd Tides, waves, and winds
94.10.Lf Convection, diffusion, mixing, turbulence, and fallout
94.10.Nh Cosmic dust
94.10.Qj Airglow and nightglow
94.10.Sm Aurora

94.20.−y Physics of the ionosphere

94.20.Bb Wave propagation
94.20.Dd Ionospheric structure (regions *D, E, F*, and topside) including steady-state ion densities and temperatures
94.20.Ee *D* region
94.20.Gg *E* region
94.20.Ji *F* region
94.20.Lk Topside region
94.20.Mm Plasmasphere
94.20.Pp Plasmapause
94.20.Qq Particle precipitation
94.20.Rr Interactions between waves and particles
94.20.Ss Electric fields
94.20.Tt Ionospheric soundings
94.20.Vv Ionospheric disturbances
94.20.Ww Plasma motion, convection, or circulation
94.20.Yx Interaction between ionosphere and magnetosphere

94.30.−d Physics of the magnetosphere

94.30.Bg Magnetic coordinate systems
94.30.Ch Magnetospheric configuration
94.30.Di Magnetopause
94.30.Ej Magnetic tail
94.30.Fk Plasma motion, convection, or circulation
94.30.Gm Plasma instabilities
94.30.Hn Trapped particles
94.30.Kq Electric fields
94.30.Lr Magnetic storms, substorms
94.30.Ms Magnetic pulsations
94.30.Nt Electrostatic waves
94.30.Pv Wave propagation
94.30.Qw ELF and ULF waves (including whistlers)
94.30.Rx VLF waves
94.30.Sy Magnetosheath
94.30.Va Interaction between solar wind and magnetosphere
94.30.Wb Interactions between magnetosphere and cosmic rays

94.40.−i Cosmic rays

94.40.Cn Origin and propagation outside the solar system
94.40.Eq Interplanetary propagation and effects
94.40.Ht Energetic solar particles and photons
94.40.Kw Solar modulation and geophysical effects
94.40.Lx Composition and energy spectra
94.40.Pa Extensive air showers
94.40.Rc High-energy interactions
94.40.Te Muons and neutrinos
94.40.Vf Cosmic-ray effects in meteorites and terrestrial matter

For planets, see 96.30

For Moon, see 96.20

94.60.−v Interplanetary space

94.60.Da Solar wind magnetic fields
94.60.Fc Solar wind electric fields
94.60.Gd Solar wind plasma
94.60.Kg Interplanetary neutral gases
94.60.Mi Interplanetary dust particles
94.60.Qm Solar wind interactions with moon and planets
94.60.Rn Shock waves
94.60.Sp Electromagnetic radiation

For other objects in the planetary system, see 96.50

94.80.−f Aerospace facilities and techniques; space research *(see also 87.65. Aerospace biophysics and medical physics)*

94.80.Px Lunar and planetary probes and satellites
94.80.Rz Artificial earth satellites
94.80.Vc Geophysical instrumentation
94.80.Wd Astrophysical instrumentation

94.90.+m Other topics in aeronomy and space physics

95. Fundamental astronomy and astrophysics; instrumentation, techniques, and astronomical observations

95.10.−a Fundamental astronomy

95.10.Ce Celestial mechanics

For dynamics and kinematics of stellar systems, see 98.10

95.10.Eg Orbit determination and improvement
95.10.Gi Astrometric aspects of eclipses, transits, and occultations
95.10.Jk Astrometry and spherical astronomy

95.30.−k Fundamental aspects of astrophysics

95.30.Cq Elementary particle and nuclear processes
95.30.Es Atomic and molecular theory and interactions
95.30.Gv Radiation mechanisms
95.30.Jx Radiative transfer
95.30.Lz Hydrodynamics
95.30.Qd Hydromagnetics and plasmas
95.30.Sf Relativity and gravitation *(see also 98.80.D. Relativistic cosmology)*

95.45.+i Observatories

95.55.−n Astronomical instruments

95.55.Br Astrometric instruments
95.55.Cs Optical telescopes
95.55.Ev Solar instruments
95.55.Jz Radiotelescopes
95.55.Lb Space instruments

95.65.+v Auxiliary and recording instruments

95.70.+i Other instrumentation and techniques (including clocks, frequency standards, etc.)

For space technology, see 93.80

95.75.−z Techniques of observation and reduction

95.75.De Photography and photometry
95.75.Fg Spectroscopy and spectrometry
95.75.Hi Polarimetry
95.75.Kk Interferometry and other special techniques
95.75.Mn Image processing
95.75.Pq Mathematical procedures and computer techniques

95.80.+p Catalogues, atlases, etc.

95.85.−e Astronomical observations (listed by technique of observation)

95.85.Dj Radio and radar
95.85.Gn Far infrared (bolometric, photoconductive)
95.85.Jq "Photographic region" (near infrared, visible, and normal ultraviolet)
95.85.Mt Space ultraviolet
95.85.Nv X ray
95.85.Qx γ ray and elementary particle
95.85.Sz Other, including gravitational radiation, magnetograms, etc.

95.90.+v Other topics in astronomy and astrophysics

96. Solar system

96.10.+i General, solar nebula, and cosmogony

96.20.−n Moon

96.20.Br Origin, formation, and age
96.20.Dt Features, landmarks, mineralogy, petrology and atmosphere
96.20.Jz Gravitational field, selenodesy, magnetic fields

96.30.−t Planets and satellites (excluding the moon)

For celestial mechanics, see 95.10.M

96.30.Dz Mercury
96.30.Ea Venus

For Earth as an astronomical body, see 91 and 92

96.30.Gc Mars
96.30.Hd Asteroids
96.30.Kf Jupiter
96.30.Mh Saturn
96.30.Tp Other planets

96.50.−e Other objects in the planetary system

96.50.Dj Interplanetary matter, magnetic and electric fields (including gegenschein and zodiacal light) *(see also 94.60. —in Geophysics)*
96.50.Gn Comets
96.50.Kr Meteors, showers, and meteoroids
96.50.Mt Meteorites, micrometeorites

96.60.−j Solar physics

96.60.Cp General, figure, rotation
96.60.Fs Chemical composition
96.60.Kx Solar interior (including neutrino problem)
96.60.Mz Photosphere, granulation
96.60.Na Chromosphere and chromosphere–corona transition
96.60.Pb Corona

96.60.Qc Sunspots, faculae, plages

96.60.Rd Flares, bursts, and related phenomena

96.60.Se Prominences and streamers

96.60.Tf Solar electromagnetic radiation

96.60.Vg Particle radiation, solar wind *(see also 94.60.D, 94.60.F, and 94.60.G for geophysical effects)*

96.90.+c Other topics on the solar system

97. Stars

97.10.−q Stellar characteristics

97.10.Bt Star formation

97.10.Cv Stellar interiors, evolution, nucleosynthesis, ages

97.10.Ex Stellar atmospheres, radiative transfer

97.10.Fy Circumstellar shells and expanding envelopes

97.10.Ha Mass loss and stellar winds

97.10.Kc Stellar rotation

97.10.Ld Magnetic and electric fields

97.10.Nf Masses

97.10.Qh Diameters and surface features

97.10.Ri Luminosities, temperatures

97.10.Tk Spectral classification, abundances

97.10.Vm Distances, parallaxes

97.10.Wn Space motions (proper motions, radial velocities)

97.20.−w Normal stars (by class): general or individual

97.20.Db Pre-main-sequence types; S, R, and N types; T Tauri

97.20.Ec Main-sequence: early-type stars (O and B)

97.20.Ge Main-sequence: intermediate type A and F stars

97.20.Jg Main-sequence: late-type stars (G, K, and M)

97.20.Li Giant and subgiant stars

97.20.Pm Supergiant stars

97.20.Rp Faint blue stars, white dwarfs, degenerate stars

97.20.Tr Population II stars

97.30.−b Variable and peculiar stars (including novas)

97.30.Eh Emission-line stars (Of, Wolf-Rayet, Be, etc.)

97.30.Fi Magnetic stars (Ap, Am, etc.)

97.30.Gj Cepheids, W Virginis, and RV Tauri stars

97.30.Jm Long-period variables and semiregulars

97.30.Kn RR Lyrae stars

97.30.Nr Flare stars

97.30.Qt Novas, dwarf novas *(see also 98.70.Q for other X-ray sources)*

97.30.Sw Other types of variables

97.60.−s Late stages of stellar evolution (including black holes)

97.60.Bw Supernovas

97.60.Gb Pulsars

97.60.Jd Neutron stars

97.60.Lf Black holes

97.60.Sm Other objects believed to be desintegrating or collapsing

97.80.−d Binary and multiple stars (including extrasolar planetary systems)

97.80.Di Visual binary or multiple stars, catalogues and atlases

97.80.Fk Spectroscopic binaries

97.80.Hn Eclipsing binaries

97.80.Jp X-ray sources *(see also 98.70.Q. X-ray and γ-ray sources)*

97.80.Kq Visual multiples

97.80.Ms Planetary systems

97.90.+j Other topics in stellar astronomy

98. Stellar systems; galactic and extragalactic objects and systems; The Universe

98.10.+z Stellar dynamics

98.20.−d Stellar clusters and associations

98.20.Ch Associations of stars (OB, T, etc.)

98.20.Ej Open clusters

98.20.Hn Globular clusters

98.40.−p Interstellar matter and nebulas

98.40.Bs Interstellar matter

98.40.Ct Interstellar molecules

98.40.Fx HI regions (interstellar clouds and 21-cm absorption lines)

98.40.Hz HII regions, emission nebulas

98.40.Ja Infrared sources (including cocoons) *also 98.70.L for other sources)*

98.40.Kb Reflection nebulas, dark clouds

98.40.Md Planetary nebulas

98.40.Ne Supernova remnants

98.50.−v The Galaxy; extragalactic objects and systems

98.50.Cz General parameters, classifications, etc.

98.50.Eb Formation, structure, content

98.50.He Red shift, distances

98.50.Kg Groups, clusters, superclusters

98.50.Lh The Galaxy; Milky Way

98.50.Mi Local group of galaxies (irregular, spiral, and elliptical galaxies in local group, Magellanic clouds)

98.50.Rn Peculiar galaxies (compact nuclei, Seyferts, Markarian objects, BL Lacertae, etc.)

98.50.Tq Intergalactic matter (including magnetic and electric fields)

98.70.−f Other objects and background radiations of unknown origin or distances

98.70.Dk Discrete radio sources

98.70.Jr Quasars

98.70.Lt IR sources *(see also 98.40.J —in nebulas)*

98.70.Qy X-ray and γ-ray sources

98.70.Sa Cosmic ray sources *(For cosmic rays, see 94.40)*

98.70.Vc Background radiations

98.80.−k Cosmology *(for observational cosmology, see 98.70.V; for origin and evolution of galaxies, see 98.50.E)*

98.80.Bp Origin and formation of the Universe (big bang, steady state, etc.)

98.80.Dr Relativistic cosmology

98.80.Ft Origin and formation of the elements

98.90.+s Other topics in galactic and extragalactic astronomy

ERRATA

Special instruction:
for "Errata" items use 99.10.+g in addition to all the codes assigned to the original article.

Kaufmann, L. R. Medsker, J. W. Nelson, and R. G. Flocchini, Phys. Rev. Lett. 37, 11 (1976).
[2]In contrast to his former information, Gentry recently informed us that the monazite samples (M1) are from the same ore body, but more than 10 km away from where the biotite with giant halos have been found.
[3]J. D. Fox, W. J. Courtney, K. W. Kemper, A. H. Lumpkin, N. R. Fletcher, and L. R. Medsker, Phys. Rev. Lett. 37, 629 (1976).
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[5]J. W. Nelson, private communication.
[6]A more detailed account of our investigations will be published elsewhere.

Commensurate Ordering in Tetrathiafulvalene-Tetracyanoquinodimethane

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Is is suggested that the first-order instability in tetrathiafulvalene-tetracyanoquinodimethane [(TTF)-(TCNQ)] at 38 K is related to the fourth-order umklapp coupling which concerns the wave vectors of the star involved in the three-dimensional periodic ordering. Within the anharmonic TCNQ interchain-coupling model, we predict that the configuration of chain deformation changes abruptly at 38 K, provided that this coupling is attractive.

The recent structural investigations[1] on (TTF)-(TCNQ) have revealed the existence of a peculiar three-dimensional ordering of the Peierls deformations ($q_b = 0.295b^*$) in the temperature range between 54 and 38 K.

Between 54 and 49 K, the most unstable wave vector has a component in the direction of alternating chains equal to $a^*/2$; below 49 K, this component starts to decrease. This effect was thoroughly discussed in the recent work by Bak and Emery,[2] where it was attributed to the bilinear coupling of the intrinsically different Peierls deformations on TCNQ and TTF chains. A similar explanation was also mentioned. but only briefly, in an earlier paper by Šaub, Barišić, and Friedel.[3] Here we accept such an interpretation of the 54-K and 49-K transitions, but for the third transition at 38 K we wish to suggest an alternative explanation to that proposed in Ref. 2.

At 38 K, q_a jumps to the commensurate value $q_a = a^*/4$ and remains pinned to this value at lower temperatures. In Ref. 2, this effect was attributed to the fourth-order umklapp coupling in which the $(a^*/4, q_b)$ wave on TCNQ chains, taken to the third power, is umklapp-coupled to the $(a^*/4, -3q_b)$ wave of the TTF chains. However, the full crystal symmetry also allows the fourth-order umklapp coupling of the waves involved in the star $(\pm a^*/4, \pm q_b)$ [Fig. 1(a)]. In principle, four coupled waves can belong either to TCNQ or to TTF chains and mix together in the fourth-order invariants. Obviously, this alternative does not imply any additional scattering at 38 K such as that expected at $-3q_b = 0.115b^*$ for the mechanism of Ref. 2.

We have performed the actual calculations in the model which retains only the coupling of the

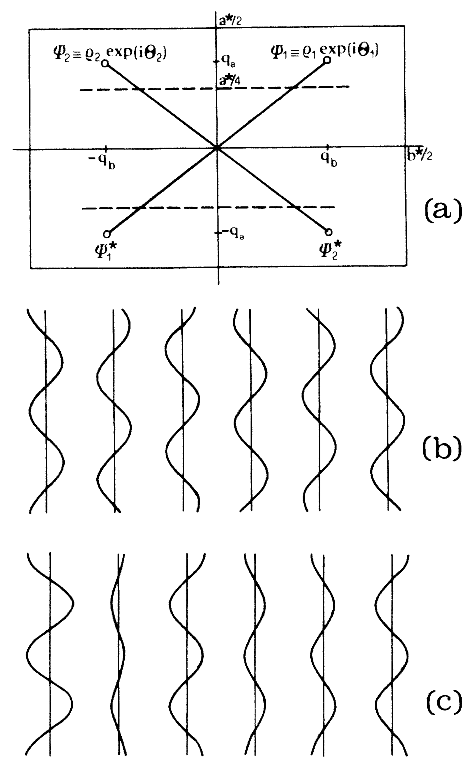

FIG. 1. (a) The star of wave vectors $(\pm q_a, \pm q_b)$. (b) The phase-shift chain deformations corresponding to the solution with only two waves ψ_1, ψ_1^* being different from zero. (c) The "amplitude-wave" configuration involving all four waves in the star with the same amplitude.

four large TCNQ waves. It will appear that the *interchain* coupling of the TCNQ waves governs the pinning effect at 38 K. This limits our model to the situations in which the strength of the TCNQ deformation compensates for the fact that the anharmonic coupling constant for the TCNQ interchain coupling is probably smaller than for the TCNQ-TTF coupling. The mixed terms are not expected to change essentially our conclusions at 38 K, but they would affect[4] the Peierls instability in the particular chain family and the sliding behavior of q_a. There is, however, no strong experimental evidence that this happens in (TTF)-(TCNQ), where the bilinear TCNQ-TTF coupling alone explains the 54–38K temperature range.

Using the notations defined in Fig. 1(a), the fourth-order terms involving TCNQ chains for $q_a < a^*/2$ are

$$b_1(\rho_1^4+\rho_2^4)+b_2'\rho_1^2\rho_2^2, \tag{1}$$

where

$$b_2' = b_2 + 2b_3\delta_{q_a,a^*/4}\cos 2(\theta_1+\theta_2). \tag{1a}$$

In general the coefficients $b_{1,2,3}$ are independent. The umklapp, phase-dependent b_3 term favors, under conditions determined below, the Peierls deformation with $q_a = a^*/4$.

The system with the anisotropic anharmonic energy (1) is stable for $b_1>0$, $b_2'/2b_1>-1$. Two different deformation configurations are then possible regarding the value of ratio $b_2'/2b_1$: (i) For $b_2'/2b_1>1$, the Landau-Ginzburg energy is minimal for $\rho_1=0$, $\rho_2=(-a/2b_1)^{1/2}$ (or vice versa), where $a\equiv a'(T-T_Q)$ and $T_Q=54$ K. The deformation on jth place in nth chain is equal to

$$2(-a/2b_1)^{1/2}\cos(q_b jb + q_a na + \theta_1), \tag{2}$$

and is shown on Fig. 1(b). q_a represents here the phase shift of the two neighboring chain waves with equal amplitudes. (ii) For $|b_2'|/2b_1<1$, $\rho_1=\rho_2=[-a/(2b_1+b_2')]^{1/2}$. This solution leads to the deformation

$$4\left[\frac{-a}{(2b_1+b_2')}\right]^{1/2}\cos\left(q_b jb+\frac{\theta_1-\theta_2}{2}\right)\cos\left(q_a na+\frac{\theta_1+\theta_2}{2}\right), \tag{3}$$

shown on Fig. 1(c). In contrast to the first case, the chain waves are not shifted relatively one to another, but instead, the amplitude depends periodically (with the period $2\pi/q_a$) upon the chain index n.

In Eqs. (2) and (3) we distinguish the phases θ_1 or $(\theta_1-\theta_2)/2$ associated with the incommensurate wave number q_b and the phase $(\theta_1+\theta_2)/2$ which in the "amplitude wave" goes with the potentially commensurate wave number q_a. When $q_a=a^*/4$, this phase appears in the fourth-order deformation energy (1). This is the lowest-order phase-dependent term built by the star of Fig. 1(a), i.e., there is no third-order invariant of such a nature.

The minimization of Eq. (1) with respect to $\theta_1+\theta_2$ gives $b_2'=b_2-2|b_3|$ and $\theta_1+\theta_2$ equal to $\pi/2$ (for $b_3>0$) or to 0 (for $b_3<0$). The condition $|b_2'|/2b_1<1$ established above for the stability of the "amplitude wave" (ii) thus becomes at 38 K the condition for the pinning of q_a on $a^*/4$, [i.e., $|b_2-2|b_3||<2b_1$]. When the fourth-order contributions are written in terms of displacements instead of the order parameters $\psi_{1,2}$, this condition amounts to the requirement that the fourth-order interchain interaction is attractive. If so, the configuration of TCNQ waves at 38 K is that of Fig. 1(c), with the amplitudes of waves equal to $2[-2a/(2b_1+b_2-2|b_3|)]^{1/2}$ (for $b_3>0$), or to 0 and $4[-a/(2b_1+b_2-2|b_3|)]^{1/2}$ (for $b_3<0$).

It remains for us to find out which of the two configurations shown in Figs. 1(b) and 1(c) is present in (TTF)-(TCNQ) between 54 and 38 K. For this purpose, we use the experimental fact that no discontinuity is observed in the TCNQ deformation in the temperature range 38 K $<T<$ 54 K.[1] This range includes the temperature $T=49$ K at which q_a starts to decrease from $a^*/2$. For $q_a=a^*/2$ [i.e., at temperatures 49 K $<T<$ 54 K], the star of Fig. 1(a) reduces to only two independent components $\psi_{\pm\pi}=\rho_\pi\exp(\pm i\theta_\pi)$. The fourth-order invariant is then of the form $b_\pi\rho_\pi^4$. With the equilibrium value $\rho_\pi=(-a/2b_\pi)^{1/2}$, the deformation is

$$2(-a/2b_\pi)^{1/2}\cos(q_b jb + n\pi+\theta_\pi). \tag{4}$$

We can compare the amplitude of the deformation (4) and the related deformation energy at 49 K with the corresponding quantities of configurations (i) and (ii). The conclusion is that only the transition from the configuration (4) to the configuration (i) can be continuous, and it is provided that $b_\pi=b_1$. Thus in our model and in the temperature range 38 K $<T<$ 49 K, the equivalent configurations $\{\rho_1\neq 0, \rho_2=0\}$ [Fig. 1(b)] and $\{\rho_1=0, \rho_2\neq 0\}$ are associated with the lowest-order free energy $(b_2>2b_1)$.[5] On a macroscopic scale, we would expect equal proportion of domains with these two structures.

The overall prediction of the present model for the first-order instability at 38 K is that, besides the discontinuity in the amplitude of chain waves, it involves the transition from the configuration with the phase shift [Fig. 1(b)] to the essentially different configuration with the "amplitude wave" in the a direction.

Our final remark concerns the excitations at and below 38 K. In the usual picture the terms of the type b_3 in Eq. 1(a) are included into the sine-Gordon equation for the phase. This leads to the soliton solution: The phase is $(q_a na + cte)$ in large regions of the crystal; these regions are separated by walls where the phase changes abruptly by the amount $2\pi/M = \pi/2$. Our feeling is that the situation is in fact more complicated, because the phase differs from $(q_a na + cte)$ in the wall and, according to Eq. 1(a), the cosine term switches off there. The question of excitations seems therefore to require further investigation, based perhaps on the continuity of the umklapp terms in the unaveraged energy.

We gratefully acknowledge clarifying discussions with R. Comès, J. R. Cooper, and J. A. Krumhansl.

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[3]K. Šaub, S. Barišić, and J. Friedel, Phys. Lett. 56A, 302 (1976).

[4]E.g. I. F. Lyuksyutov, Phys. Lett. 56A, 135 (1976).

[5]The same conclusion can be drawn from the model of the predominantly local (intrachain) fourth-order coupling.