#### CHAPTER 4. STATICS OF THE SUSPENDED STRING OR CABLE

Introduction, 73. Light Cable Supporting a Horizontal Roadway; the Suspension Bridge, 73. Uniform Cable Supporting Its Own Weight; the Uniform Catenary, 75. Points of Support Not at the Same Level, 77. Determination of the Parameter c of the Catenary, 79. Approximate Determination of the Parameter c for a Tightly Stretched String, 80. Parabolic Catenary, 81. Catenary of Uniform Strength 81. Heavy String or Cable Subject to Smooth Constraint, 83. Problems, 84.

#### CHAPTER 5. WORK AND THE STABILITY OF EQUILIBRIUM . . 86

Work and Potential Energy

Work Done by a Force, 86. Potential Energy and the Conservative Field, 87. Work Required to Raise a System of Particles at the Earth's Surface; the Uniform Field, 89. Conservation of Energy; Kinetic Energy, 90. Work Required to Stretch an Elastic String, 91.

The Law of Gravitation

Origin and Statement of the Law; Gravitational Field Strength, 92. Potential Energy in a Gravitational Field; Potential, 93. Field and Potential of an Extended Body, 93. Field and Potential of a Homogeneous Spherical Body, 95. Principle of Virtual Work

Applied Forces and Forces of Constraint; Virtual Displacements, 97. Equilibrium and Finite Displacements; the Pulleys of Stevinus and the Inclined Plane of Galileo, 98. Infinitesimal Virtual Displacements; Statement of the Principle of Virtual Work, 100. Work Done by Internal Forces, 102. Miscellaneous Examples, 104.

Stability of Equilibrium

Equilibrium of Conservative Forces, 107. Potential Energy a Function of a Single Scalar Variable, 108. Problems, 112.

# CHAPTER 6. MOTION OF A PARTICLE IN A UNIFORM FIELD . . 116

One-dimensional Motion of a Particle Acted upon by a Constant Force Falling Body, 116. Particle on a Smooth Inclined Plane, 118. Atwood's Machine, 118. Kinetic Friction, 120.

Flight of a Projectile

Projectile in a Vacuum; Equation of the Path, 124. Miscellaneous Examples, 125. Falling Body; Resistance Proportional to the First Power of the Velocity, 128. Resistance Proportional to the Second Power of Velocity, 129. Projectile with Air Resistance, 130. Problems, 132.

CHAPTER 7. OSCILLATORY MOTION OF A PARTICLE IN ONE DI-MENSION

Motion of a Simple Pendulum; the Oscillator Equation, 135. Physical Interpretation of Terms, 137. Exponential Method of Solution, 138. Energy of the Oscillator, 138.

The Damped Harmonic Oscillator

The General Solution; the Underdamped Case, 139. Critically Damped and Overdamped Cases, 142.

The Forced Harmonic Oscillator

General Solution, 144. Resonance, 146. Rate at Which Work Is Being Done, 149. Application to an Elastically Bound Electron, 151.

Х

73

153

Departures from Harmonic Oscillations

Natural Period of the Undamped System, 152. Forced Motion of an Undamped Nonlinear System, 153. Thermal Expansion of a Crystal, 155. Problems, 157.

## CHAPTER 8. MOTION OF A SYSTEM OF PARTICLES . . . . 160

Linear and Angular Momentum for a Single Particle, 160. System of Particles

Linear Momentum of the Center of Mass of a System, 162. Angular Momentum of a System of Particles, 164. Torque Equation with Reference to an Arbitrary Origin, 165. Int Ethergy of a System of Particles, 168. Angular Momentum of a System of Particles in Terms of the Center of Mass, 170] Relative Motion of Two Bodies; the Reduced Mass, 171] Impulsive Forces and Impact

Nature of an Impulse, 173. Impact, Elastic and Inelastic; Coefficient of Restitution, 175. Motion Relative to the Center of Mass. Loss of Energy during Impact, 179. Generalization of Newton's Rule; Oblique Impact of Two Smooth Spheres, 180. Comparison of the Rest and Center-of-mass Systems of Coordinates for the Oblique Impact of Two Particles, 182.

Motion of a Body When the Mass Varies

Finding the Correct Equation of Motion When the Mass Varies, 184. Motion of a Rocket-propelled Body, 186. Problems, 187.

#### CHAPTERS. MOTION OFARIGID BODY IN A PLANE . . . 192

Specification of a Rigid Body, 192. General Displacement of a Rigid Body 193. Space and Body Centrodes for Velocity; Point of Instantaneous Rest,' 194. Infinitesimal Rotations and the Angular-velocity Vector, 197]

Dynamics of a Rigid Body in a Plane

Kinetic Energy of Rotation; the Moment of Inertia, 199] Angular Momentum of a Rigid Body Moving Parallel to a Fixed Plane; the Rotational Equation of Motion, 200. Theorem of Parallel Axes, 201. Calculation of Moments of Inertia, 262. Coordinate Systems for Rigid Bodies, 203 The Compound Pendulum, 205. Use of the Instantaneous Axis, 207 Rolling and Sliding Motion of a Sphere, 209.

Impulsive Motion of a Rigid Body in a Plane

Impulsive Torque, 211. Center of Percussion, 212. Newton's Rule for the Smooth Impact of Two Extended Bodies, 213. Connected Systems, 216. Problems, 217.

#### CHAPTER 10. MOTION OF A PARTICLE UNDER THE ACTION OF A CENTRAL FORCE

Kinetic Energy in Plane Polar Coordinates, 223. Acceleration in Plane Polar Coordinates, 224. Areal Velocity and Angular Momentum of a Particle Moving in a Central Field, 225.

Inverse-square Field : The Orbit

Integration of the Equations of Motion, 227. Equation of the Orbit by the Encry Method, 230. Energy and Classification of the Orbits, 232. Kepler's Laws

Statement of Kepler's Laws, 234. Dedc ton of the Law of Force from Kepler's Laws, 236. The Two-body Problem and Kepler's Third Law, 236. Disturbed Circular Orbits

Stability of Circular Orbits, 237.

223

## Apsides

Apsidal Distances and Apsidal Angles, 240. Apsides in a Nearly Circular Orbit; Advance of the Perihelion, 242. Problems, 244.

## CHAPTER 11. ACCELERATED REFERENCE SYSTEMS AND CON-STRAINED MOTION OF A PARTICLE. . . . . 248

Motion of a Particle in an Accelerated Reference System Nature of the Problem, 248. Calculation of the Inertial Reaction in a Moving Frame, 249. Application of the Principles, 252. The Foucault Pendulum, 255. Motion of a Particle along a **Surface or a Curve** Introductory Examples, 257. Motion along a Smooth Plane Curve; Normal and Tangential Accelerations, 259. More General Treatment of Integrable Constraints; Motion Confined to a Smooth Surface of Arbitrary Form, 261. Equation of Energy, 262. The Angular-momentum Integral, 263. Rough Constraints; Particle Sliding on a Rough Wire, 266. The Pendulum of Arbitrary Amplitude, 267. Problems, 269.

#### CHAPTER 12. MOTION OF A RIGID BODY IN THREE DIMENSIONS 272

The Instantaneous Axis, 272. Angular Momentum in Term8 of Its Components; Moment8 and Product8 of Inertia, 273. Principal Axes, 275. Determination of the Other Two Principal Axes When One 18 Given, 278. Centrifugal Reactions; Dynamically Balanced Body, 280. Moment of Inertia about an Arbitrary Axis; Ellipsoid of Inertia, 282. Rotational Kinetic Energy of a Rigid Body, 285. Description of the Free Rotation of a Rigid Body in Term8 of the Ellipsoid of Inertia, 287. Classes of Problems to Be Considered in Rigid Dynamics, 289. Motion of a Rigid Body Referred to Rotating Axes; Euler'8 Dynamical Equations, 290. Constancy of Energy and Angular Momentum by Means of Euler'8 Equations, 291. Free Rotation of the Earth, 292. Free Motion of a Rigid Body Referred to Axes Having a Fixed Direction in Space; Motion of the Earth, 296.

Motion of a Top

Choice of Coordinates; Equation8 of Motion, 302. Energy and Angularmomentum Integrals, 305. Limits of the ∅ Motion, 307. Precession with Nutation, 309. Precession without Nutation, 309. The Sleeping Top, 312. Gyroscopid Action; the Rising Top, 313. Problems, 314.

## CHAPTER 13. GENERALIZED COORDINATES. .

Holonomic and Nonholonomic Constraints; Degrees of Freedom, 317. Kinetic Energy in Curvilinear Coordinates, 319. Generalized Coordinates; Lagrange'8 Equations for a Single Particle, 322. Lagrange's Equations for a System of Particles, 330. Generalized Momentum, 331. Motion of a Symmetrical Top from Lagrange's Equations, 332. The Hamiltonian Function; Hamilton's Equations, 334. Problems, 339.

#### CHAPTER 14. VIBRATING SYSTEMS AND NORMAL COORDINATES 341

317

Coupled Pendulums, 342. Normal Coordinates, 344. Equations of Motion and the Energy in Term8 of Normal Coordinates, 345. Transfer of Energy from One Pendulum to the Other, 346. Possibility of Expressing an Arbitrary System in Terms of Normal Coordinates, 348. Dissipative Systems, 353. Forced Oscillations, 355. Vibration8 of Molecules, 357. Summary of Properties of Normal Coordinates, 358.

CHAPTER 15. VIBRATING STRINGS AND WAVE MOTION	362
Equations of Motion, 362. General Solution, 363. Determination of the Coefficients $A_n$ and $B_n$ 365. Energy and Normal Coordinates of a Vibrating String, 367. Damped and Forced Motion of a Vibrating String, 370 Transverse Wave Motion in a String	
Traveling-wave Solution, 372. Terminal Conditions and Initial Conditions 375. More General Discussion of Effect of Initial Condition8 378 Standing Waves, 380. Behavior at a Junction; Energy Flow, 381. Problems, 383.	
APPENDIX 1. AREA AND VOLUME ELEMENTS IN COMMON CO- ORDINATE SYSTEMS	385
Plane Polar Coordinates, 385. Spherical Polar Coordinates, 385. Cylindrical Polar Coordinates, 386.	
APPENDIX 2. ELEMENTS OF ORDINARY DIFFERENTIAL EQUA- TIONS	387
The Nature of Differential Equations, 387. The Nature of the Solution of a Differential Equation, 388. Formation of Differential Equation8 by Elimination of Constants, 389. Equations of the First Order Exact Equations, 389. Solution by Separation of Variables, 390. Integrating Factors, 390. The Linear Equation of the First Order, 391. Nonlinear First-order Equations, 392. Equations of the Second and Higher Orders Linear with Constant Coefficients; Right Side Equal to Zero, 293. The Case of Equal Roots, 394. The Operator <b>D</b> , <b>395.</b> Linear Equations with Constant Coefficients; Right Side Not Equal to Zero, 397. Miscellaneous Method8 for Equations of Order Higher Than the First The Equation Does Not Contain <i>w</i> Explicitly, 399. The Equation Does Not Contain <i>w</i> Explicitly, 399. The Equation Does Not Contain <i>w</i> Explicitly, 399. Procedure When One Integral Belonging to the Complementary Function Is Known, 400. Problems, 401.	
APPENDIX 3. NOTE ON HYPERBOLIC FUNCTIONS	402
APPENDIX 4. COMMONLY EMPLOYED EXPRESSIONS INVOLVING PARTIAL DERIVATIVES	404
APPENDIX 5. NOTE ON FOURIER SERIES	406
Problems, 412	
INDEX	413

x111