

# Appendix A

## Some Useful Vector Formulas

### A.1 Gradient, Curl, Divergence and Laplacian

Vector equations are independent of the coordinate system used. Cartesian coordinates are used very often because they are the most convenient when the problem has no particular symmetry. However, in the case of particular symmetries, calculations can be greatly facilitated by a suitable choice of the coordinate system. Apart from the elliptical coordinates, used only in Problem 2.14, The only two special systems used in this book are the cylindrical and spherical coordinates.

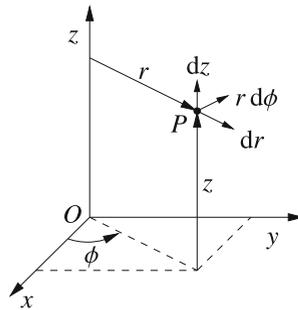


Fig. A.1

A cylindrical coordinate system  $(r, \phi, z)$  specifies a point position by the distance  $r$  from a chosen reference (*longitudinal*) axis  $z$ , the angle  $\phi$  that  $r$  forms with a chosen reference plane  $\phi = 0$  containing the  $z$  axis, and the distance, positive or negative, from a chosen reference plane perpendicular to the axis. The origin is the point where  $r$  and  $z$  are zero, for  $r = 0$  the value of  $\phi$  is irrelevant. Fig. A.1 shows a cylindrical coordinate system, superposed to a Cartesian system sharing the same origin, with the  $z$  axes of the two systems are superposed, the  $xz$  plane corresponding to the  $\phi = 0$  plane of the cylindrical system. We have the conversion relations

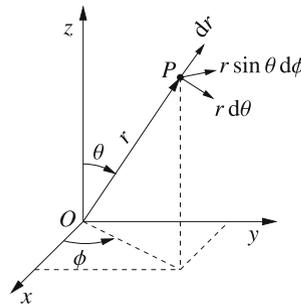


Fig. A.2

**Table A.1** Gradient, curl, divergence and Laplacian in cylindrical and spherical coordinates

Cylindrical Coordinates	Spherical Coordinates
Components of the gradient of a scalar function $V$	
$\hat{\mathbf{r}} \frac{\partial V}{\partial r}$ $\hat{\boldsymbol{\phi}} \frac{1}{r} \frac{\partial V}{\partial \phi}$ $\hat{\mathbf{z}} \frac{\partial V}{\partial z}$	$\hat{\mathbf{r}} \frac{\partial V}{\partial r}$ $\hat{\boldsymbol{\theta}} \frac{\partial V}{\partial \theta}$ $\hat{\boldsymbol{\phi}} \frac{1}{r \sin \theta} \frac{\partial V}{\partial \phi}$
Components of the curl of a vector function $\mathbf{A}$	
$\hat{\mathbf{r}} \left( \frac{1}{r} \frac{\partial A_z}{\partial \phi} - \frac{\partial A_\phi}{\partial z} \right)$ $\hat{\boldsymbol{\phi}} \left( \frac{\partial A_r}{\partial z} - \frac{\partial A_z}{\partial r} \right)$ $\hat{\mathbf{z}} \frac{1}{r} \left[ \frac{\partial(rA_\phi)}{\partial r} - \frac{\partial A_r}{\partial \phi} \right]$	$\hat{\mathbf{r}} \frac{1}{r \sin \theta} \left[ \frac{\partial}{\partial \theta} (A_\phi \sin \theta - \frac{\partial A_\theta}{\partial \phi}) \right]$ $\hat{\boldsymbol{\theta}} \left[ \frac{1}{r \sin \theta} \frac{\partial A_r}{\partial \phi} - \frac{1}{r} \frac{\partial(rA_\phi)}{\partial r} \right]$ $\hat{\boldsymbol{\phi}} \frac{1}{r} \left[ \frac{\partial(rA_\theta)}{\partial r} - \frac{\partial A_r}{\partial \theta} \right]$
Divergence of a vector function $\mathbf{A}$	
$\frac{1}{r} \frac{\partial(rA_r)}{\partial r} + \frac{1}{r} \frac{\partial A_\phi}{\partial \phi} + \frac{\partial A_z}{\partial z}$	$\frac{1}{r^2} \frac{\partial(r^2 A_r)}{\partial r} + \frac{1}{r \sin \theta} \frac{\partial(A_\theta \sin \theta)}{\partial \theta} + \frac{1}{r \sin \theta} \frac{\partial A_\phi}{\partial \phi}$
Laplacian of a scalar function $V$	
$\frac{1}{r} \frac{\partial}{\partial r} \left( r \frac{\partial V}{\partial r} \right) + \frac{1}{r^2} \frac{\partial^2 V}{\partial \phi^2} + \frac{\partial^2 V}{\partial z^2}$	$\frac{1}{r^2} \frac{\partial}{\partial r} \left( r^2 \frac{\partial V}{\partial r} \right) + \frac{1}{r^2 \sin \theta} \frac{\partial}{\partial \theta} \left( \sin \theta \frac{\partial V}{\partial \theta} \right) + \frac{1}{r^2 \sin^2 \theta} \frac{\partial^2 V}{\partial \phi^2}$

$$x = r \cos \phi, \quad y = r \sin \phi, \quad z = z. \quad (\text{A.1})$$

The orthogonal line elements are  $dr$ ,  $r d\phi$  and  $dz$ , and the infinitesimal volume element is  $r dr d\phi dz$ .

A spherical coordinate system  $(r, \theta, \phi)$  specifies a point position by the radial distance  $r$  from from a fixed origin, a polar angle  $\theta$  measured from a fixed zenith direction, and the azimuth angle  $\phi$  of the orthogonal projection of  $r$  on a reference plane that passes through the origin and is orthogonal to the zenith, measured from a fixed reference direction on that plane. Fig. A.2 shows a spherical coordinate system, superposed to a Cartesian system sharing the same, origin, with the  $z$  axis superposed to the zenith axis, and the  $xz$  plane corresponding to the  $\phi = 0$  plane of the spherical system. We have the conversion relations

$$x = r \sin \theta \cos \phi, \quad y = r \sin \theta \sin \phi, \quad z = r \cos \theta. \quad (\text{A.2})$$

The orthogonal line elements are  $dr$ ,  $r d\theta$ , and  $r \sin \theta d\phi$ , and the infinitesimal volume element is  $r^2 \sin \theta d\theta d\phi dr$  (Table A.1).

## A.2 Vector Identities

Quantities  $\mathbf{A}$ ,  $\mathbf{B}$ , and  $\mathbf{C}$  are vectors or vector functions of the coordinates,  $f$  and  $g$  are scalar functions of the coordinates.

$$\mathbf{A} \cdot \mathbf{B} \times \mathbf{C} = \mathbf{A} \times \mathbf{B} \cdot \mathbf{C} = \mathbf{B} \cdot \mathbf{C} \times \mathbf{A} = \mathbf{C} \cdot \mathbf{A} \times \mathbf{B}; \quad (\text{A.3})$$

$$\mathbf{A} \times (\mathbf{B} \times \mathbf{C}) = (\mathbf{C} \times \mathbf{B}) \times \mathbf{A} = (\mathbf{A} \cdot \mathbf{C})\mathbf{B} - (\mathbf{A} \cdot \mathbf{B})\mathbf{C}; \quad (\text{A.4})$$

$$\nabla(fg) = f \nabla g + g \nabla f; \quad (\text{A.5})$$

$$\nabla \cdot (f\mathbf{A}) = f \nabla \cdot \mathbf{A} + \mathbf{A} \cdot \nabla f; \quad (\text{A.6})$$

$$\nabla \times (f\mathbf{A}) = f \nabla \times \mathbf{A} + \nabla f \times \mathbf{A}; \quad (\text{A.7})$$

$$\nabla \cdot (\mathbf{A} \times \mathbf{B}) = \mathbf{B} \cdot \nabla \times \mathbf{A} - \mathbf{A} \cdot \nabla \times \mathbf{B}; \quad (\text{A.8})$$

$$\nabla \times (\mathbf{A} \times \mathbf{B}) = \mathbf{A}(\nabla \cdot \mathbf{B}) - \mathbf{B}(\nabla \cdot \mathbf{A}) + (\mathbf{B} \cdot \nabla)\mathbf{A} - (\mathbf{A} \cdot \nabla)\mathbf{B}; \quad (\text{A.9})$$

$$\nabla(\mathbf{A} \cdot \mathbf{B}) = \mathbf{A} \times (\nabla \times \mathbf{B}) + \mathbf{B} \times (\nabla \times \mathbf{A}) + (\mathbf{A} \cdot \nabla)\mathbf{B} + (\mathbf{B} \cdot \nabla)\mathbf{A}; \quad (\text{A.10})$$

$$\nabla^2 \mathbf{A} = \nabla(\nabla \cdot \mathbf{A}) - \nabla \times (\nabla \times \mathbf{A}), \quad (\text{A.11})$$

$$\nabla \times (\nabla \times \mathbf{A}) = \nabla(\nabla \cdot \mathbf{A}) - \nabla^2 \mathbf{A}. \quad (\text{A.12})$$

# Index

## A

Absorbing medium, radiation pressure on an, 113, 436  
Alternate LC ladder network, 59, 285  
Amplitude reflection coefficient, 99, 391  
Angle of incidence, 76  
Angle of reflection, 76  
Angular momentum of a light beam, 69, 312  
Antenna, circular, 82, 349  
Anti-reflection coating, 90, 369  
Atomic collapse, 80, 342  
Avogadro constant, 137

## B

Beam, Gaussian, 69, 310  
Beats, optical, 84, 356  
Bent dipole antenna, 82, 348  
Birefringence, 90, 91, 370, 371  
Boundary conditions on a moving mirror, 77, 335

## C

Cable, twin-lead, 96, 384  
Capacitance per unit length, 95, 381  
Capacitor, leaky, 200  
Capacity of a conducting cylindrical wire, 15, 164  
Capacity of a cylindrical wire, 167  
Capacity per unit length, 281  
Cavity, optomechanical, 113, 434  
Charged hemispherical surface, 8, 134  
Charge distribution in the presence of electrical current, 30, 205  
Charged sphere, electrostatic energy of a uniformly, 4, 119

Charged spheres, collision, 7, 130  
Charged spheres, overlapping, 3, 117  
Charged sphere with internal spherical cavity, 4, 118  
Charged wire in front of a cylindrical conductor, 14, 155  
Charge in front of a dielectric half-space, 19, 169  
Charge relaxation, 27, 194  
Circular antenna, 82, 349  
CL ladder network, 58, 282  
CO<sub>2</sub>, 103  
Coating, anti-reflection, 90, 369  
Coaxial cable, 95, 381  
Coaxial resistor, 27, 196  
Coil in an inhomogeneous magnetic field, 44, 231  
Collapse, atomic, 80, 342  
Collision of two charged spheres, 7, 130  
Conducting foil, transmission and reflection, 89, 367  
Conducting half-space, 23, 187  
Conducting plane, charge in front of a, 10, 138, 142  
Conducting prolate ellipsoid of revolution, 15, 164  
Conducting shell, point charge inside a, 13, 154  
Conducting slab, 20, 176  
Conducting sphere, electric charge in front of a, 11, 144  
Conducting sphere, electric dipole in front of a, 11, 146  
Conducting sphere, electromagnetic torque on a, 108, 419  
Conducting sphere in an external field, 10, 137

Conducting sphere in a uniform electric field, 12, 151  
 Conducting sphere, plasma oscillations in a charged, 7, 131  
 Conducting sphere, scattering from a perfectly, 114, 438  
 Conducting surface, hemispherical, 14, 159  
 Conductors, displacement current in, 256  
 Conductor, wave propagation in a, 88, 361  
 Coulomb explosion, infinite charged cylinder, 6, 127  
 Coulomb explosion, infinite charged slab, 6, 127  
 Coulomb explosion, uniformly charged sphere, 5, 124  
 Coulomb's experiment, 11, 148  
 Coupled *RLC* oscillators, 56, 57, 273, 276  
 Crossed electric and magnetic fields, 39, 220  
 Currents and charge distribution in conductors, 29, 201  
 Cutoff frequency, 388  
 Cyclotron radiation, 79, 339  
 Cyclotron resonances, 60, 61, 290, 293  
 Cylinder, transversally polarized, 23, 188  
 Cylinder, uniformly magnetized, 38, 219  
 Cylindrical capacitor, 22, 184  
 Cylindrical capacitor, discharge of a, 105, 405  
 Cylindrical conductor, charged wire in front of a, 14, 155  
 Cylindrical conductor with an off-center cavity, 39, 222  
 Cylindrical wire, capacity of a conducting, 15, 164

**D**

Damping, radiative, 80, 343  
 DC generator, magnetized cylinder, 49, 249  
 Dielectric-barrier discharge, 29, 204  
 Dielectric boundary conditions, 176  
 Dielectric half-space, 20, 176  
 Dielectric, lossy, 29, 202  
 Dielectric permittivity, measurement of the, 22, 184  
 Dielectric Slab, 23, 187  
 Dielectric sphere in an external field, 20, 173  
 Dipole antenna, bent, 82, 348  
 Discharge of a cylindrical capacitor, 105, 405  
 Disk, Faraday, 49, 251

Displacement current in conductors, 256  
 Distortionless transmission line, 58, 283  
 Drag force, radiation, 115, 442  
 Dynamo, self-sustained, 49, 251

**E**

Earth's magnetic field, 46  
 Eddy currents in a solenoid, 46, 236  
 Eddy inductance, 51, 255  
 Effect, Fizeau, 109, 423  
 Elastically bound electron, 80, 343  
 Electrically connected spheres, 13, 153  
 Electrically polarized cylinder, 103, 397  
 Electrically polarized sphere, 19, 172  
 Electric charge in front of a conducting plane, 10, 138, 142  
 Electric charge in front of a conducting sphere, 11, 144  
 Electric currents induced in the ocean, 47, 242  
 Electric dipole, force between a point charge and an, 7, 132  
 Electric dipole in a conducting spherical shell, 12, 151  
 Electric dipole in a uniform electric field, 12, 151  
 Electric dipole in front of a conducting sphere, 11, 146  
 Electric power transmission line, 96  
 Electric susceptibility, 22, 184  
 Electromagnetic torque on a conducting sphere, 108, 419  
 Electron, elastically bound, 80, 343  
 Electron gas, free, 88, 363  
 Electrostatic energy in the presence of image charges, 10, 138  
 Electrostatic pressure, 15, 21, 160, 162, 181, 183  
 Energy and momentum flow close to a perfect mirror, 106, 411  
 Energy densities in a free electron gas, 88, 363  
 Energy of a uniformly charged sphere, 4, 119  
 Equipotential surfaces, intersecting, 151  
 Equivalent magnetic charge, 39, 219  
 Evanescent wave, 88, 361  
 Experiment, the Rowland, 37, 211

**F**

Faraday disk, 49, 251  
 Faraday effect, 91, 371

Ferrite, 238  
 Ferroelectricity, 19, 172  
 Feynman's paradox, 47, 239  
 Feynman's paradox (cylinder), 70, 314  
 Fiber, optical, 99, 391  
 Fields generated by spatially periodic surface sources, 105, 408  
 Fields of a current-carrying wire, 74, 319  
 Fields of a plane capacitor, 74, 323  
 Fields of a solenoid, 75, 324  
 Filled waveguide, 100, 393  
 Fizeau effect, 109, 423  
 Floating conducting sphere, 21, 181  
 Fluid, resistivity, 28, 198, 199  
 Force between a point charge and an electric dipole, 7, 132  
 Force between the plates of a parallel-plate capacitor, 15, 160  
 Force on a magnetic monopole, Lorentz transformation for the, 75, 327  
 Four-potential of a plane wave, 75, 325  
 Free electron gas, 88, 363  
 Free fall in a magnetic field, 45, 232  
 Frictional force, radiation, 85, 357

## H

Heating, induction, 48, 246  
 Heaviside step function, 127  
 Hemispherical conducting surface, 14, 159  
 Hemispherical surface, charged, 8, 134  
 Homopolar motor, 53, 266

## I

Image charges, method, hemispherical conducting surfaces, 14, 159  
 Image charges, method of, 10, 138, 142  
 Image charges, method of, cylindrical conductor, 14, 155  
 Immersed Cylinder, 22, 185  
 Impedance of an infinite ladder network, 104, 402  
 Impedance per unit length, cylindrical wire, 51, 255, 258  
 Incidence angle, 76  
 Inductance per unit length, 95, 381  
 Induction heating, 48, 246  
 Infinite charged Cylinder, Coulomb explosion, 6, 127  
 Infinite charged slab, Coulomb explosion, 6, 127  
 Infinite ladder network, impedance, 104, 402

Infinite resistor ladder, 31, 209  
 Intensity of a light beam, 69, 312  
 Interference in Scattering, 84, 355  
 Internal spherical cavity in a charged sphere with, 4, 118  
 Intersecting equipotential surfaces, 151  
 Isolated system, 161

## L

Ladder network, *CL*, 58, 282  
 Ladder network, *LC*, 57, 279  
 Ladder network, *LC*, alternate, 59, 285  
 Laser cooling of a mirror, 106, 413  
 LC ladder network, 57, 279  
 Leaky capacitor, 200  
 Levitation, magnetic, 38, 217  
 Light beam, angular momentum of a, 69, 312  
 Light beam, Intensity of a, 69, 312  
 Lighthouse, 84, 356  
 Linear molecule, 114, 439  
 Longitudinal waves, 89, 365  
 Longitudinal waves, Lorentz transformations for, 110, 425  
 Lorentz transformation for the force on a magnetic monopole, 75, 327  
 Lorentz transformations for a transmission cable, 110, 426  
 Lorentz transformations for longitudinal waves, 110, 425  
 Lossy dielectric, 29, 202

## M

Magnetic birefringence, 91, 371  
 Magnetic charge, equivalent, 39, 219  
 Magnetic dipole in front of a magnetic half-space, 38, 214  
 Magnetic dipole, potential energy of a, 217  
 Magnetic dipole rotating inside a solenoid, 51, 254  
 Magnetic field, cylinder rotating in, 40, 223  
 Magnetic field, Earth's, 45, 234  
 Magnetic field of a rotating cylindrical capacitor, 40, 224  
 Magnetic levitation, 38, 217  
 Magnetic monopole, 71, 316  
 Magnetic monopole, Lorentz transformation for the force on a, 75, 327  
 Magnetic pressure on a solenoid, 52, 264  
 Magnetized cylinder, 38, 103, 219, 397  
 Magnetized cylinder, DC generator, 49, 249  
 Magnetized sphere, 40, 225

Magnetized sphere, unipolar motor, 48, 243  
 Maxwell's equations in the presence of magnetic monopoles, 71, 316  
 Maxwell stress tensor, 309  
 Metal sphere in an external field, 10, 137  
 Method of image charges, 10, 138, 142  
 Method of image charges, cylindrical conductor, 14, 155  
 Method of image charges, hemispherical conducting surfaces, 14, 159  
 Mie oscillations, 5, 122  
 Mie resonance and a "plasmonic metamaterial", 94, 377  
 Mirror, laser cooling of a, 106, 413  
 Mirror, moving, 76, 77, 328  
 Mirror, radiation pressure on a perfect, 68, 307  
 Monopole, magnetic, 71, 316  
 Motion of a charge in crossed electric and magnetic fields, 39, 220  
 Motor, homopolar, 53, 266  
 Moving end, waveguide with a, 111, 429  
 Moving mirror, 76, 77, 328  
 Moving mirror, boundary conditions, 77, 335  
 Moving mirror, conservation laws in, 77, 328  
 Moving mirror, oblique incidence on a, 76, 332  
 Moving mirror, radiation pressure on a, 77, 333  
 Mutual induction between a solenoid and an internal loop, 51, 254  
 Mutual induction between circular loops, 50, 253  
 Mutual induction, rotating loop, 50, 253

**N**

Network, *CL*, 58, 282  
 Network, *LC*, 57, 279  
 Neutron star, 81, 340, 347  
 Non-dispersive line, 58, 283  
 Non-uniform resistivity, 29, 201

**O**

Oblique incidence on a moving mirror, 76, 332  
 Ocean, induced electric currents, 47, 242  
 Open waveguide, TEM and TM modes in an, 97, 385  
 Optical beats, 84, 356  
 Optical fiber, 99, 391

Optomechanical cavity, 113, 434  
 Orbiting charges, radiation emitted by two, 81, 345  
 Oscillations, Mie, 5, 122  
 Oscillations of a triatomic molecule, 103, 401  
 Oscillators, coupled, 56, 57, 273, 276  
 Overlapping charged spheres, 3, 117

**P**

Pair plasma, 93, 375  
 Parallel-plate capacitor, force between the plates of a, 15, 160  
 Parallel-wire transmission line, 96, 384  
 Perfect mirror, energy and momentum flow close to a, 106, 411  
 Pinch effect, 37, 52, 212, 261  
 Plane capacitor, fields of a, 74, 323  
 Plane wave, four-potential of a, 75, 325  
 Plasma oscillations, 5, 121  
 Plasma oscillations in a charged conducting sphere, 7, 131  
 Plasma, "pair", 93, 375  
 Plasmonic metamaterial, 94, 377  
 Plasmons, 366  
 Point charge inside a conducting shell, 13, 154  
 Polaritons, 366  
 Polarization of scattered radiation, 83, 351  
 Polarization, Thomson scattering, 83, 352  
 Potential energy of a magnetic dipole, 217  
 Poynting vector for a Gaussian light beam, 69, 310  
 Poynting vector in a capacitor, 67, 301  
 Poynting vector in a capacitor with moving plates, 68, 303  
 Poynting vector in a solenoid, 67, 302  
 Poynting vector in a straight wire, 67, 299  
 Pressure, electrostatic, 15, 160, 162, 183  
 Propagation of a "relativistically" strong electromagnetic wave, 111, 431  
 Pulsar, 81, 347

**Q**

Quasi-Gaussian wave packet, 61, 295

**R**

Radiation, cyclotron, 79, 339  
 Radiation drag force, 115, 442  
 Radiation emitted by two orbiting charges, 81, 345

Radiation frictional force, 85, 357  
 Radiation pressure on a moving mirror, 77, 333  
 Radiation pressure on an absorbing medium, 113, 436  
 Radiation pressure on a perfect mirror, 68, 307  
 Radiation pressure on a thin foil, 107, 414  
 Radiation, undulator, 108  
 Radiative damping, 80, 343  
 Receiving circular antenna, 82, 349  
 Reflection angle, 76  
 Reflection by a thin conducting foil, 89, 367  
 Reflection coefficient, amplitude, 99, 391  
 Refraction of the electric field at a dielectric boundary, 20, 175  
 Relativistically strong electromagnetic wave, propagation of a, 111, 431  
 Resistivity, fluid, 28, 198, 199  
 Resistivity, non-uniform, 29, 201  
 Resistor, coaxial, 27, 196  
 Resistor ladder, infinite, 31, 209  
 Resonance, Schumann, 100, 394  
 Resonances in an *LC* ladder network, 60, 288  
 Rotating cylinder in magnetic field, 40, 223  
 Rotating cylindrical capacitor, 40, 224  
 Rotation induced by electromagnetic induction, 47, 70, 239, 314  
 Rowland experiment, 37, 211

**S**

Satellite, tethered, 45, 234  
 Scattered radiation, polarization of, 83, 351  
 Scattering and Interference, 84, 355  
 Scattering from a perfectly conducting sphere, 114, 438  
 Schumann resonances, 100, 394  
 Self-sustained dynamo, 49, 251  
 Skin effect, 51, 255  
 Slowly Varying Current Approximation (SVCA), 236  
 Solenoid, eddy currents in a, 46, 236  
 Solenoid, electric current in a, 112, 433  
 Solenoid, fields of a, 75, 324  
 Solenoid, magnetic dipole rotating inside a, 51, 254  
 Solenoid, magnetic pressure on a, 52, 264  
 Solenoid, mutual induction between an internal loop and a, 51, 254  
 Soliton, 432  
 Spatially periodic surface sources, 105, 408

Sphere, electrically polarized, 19, 172  
 Spheres, electrically connected, 13, 153  
 Sphere, uniformly magnetized, 40, 225  
 Spiral motion, 79, 339  
 Square wave generator, 44, 229  
 Square waveguides, 387  
 Square wave packet, 68, 77, 307, 333  
 Stress tensor, Maxwell, 309  
 Surface charge density, 10, 142  
 Surface charges, 20, 23, 176, 187  
 Surface waves, 93, 376  
 Surface waves in a thin foil, 109, 421

**T**

TEM and TM modes in an “open” waveguide, 97, 385  
 Tethered satellite, 45, 234  
 Thin foil, radiation pressure on a, 107, 414  
 Thin foil, surface waves in a, 109, 421  
 Thin foil, transmission and reflection, 89, 367  
 Thomson scattering in the presence of a magnetic field, 107, 417  
 Thomson scattering, polarization, 83, 352  
 Tolman-Stewart experiment, 26, 193  
 Transmission and reflection by a thin conducting foil, 89, 367  
 Transmission cable, Lorentz transformations for a, 110, 426  
 Transmission line, parallel-wire, 96, 384  
 Transversally polarized cylinder, 23, 188  
 Triangular waveguides, 387  
 Triatomic molecule, oscillations, 103, 401  
 Twin-lead cable, 96, 384

**U**

Undulator radiation, 108, 417  
 Uniformly charged sphere, Coulomb explosion, 5, 124  
 Unipolar machine, 49, 249  
 Unipolar motor, magnetized sphere, 48, 243

**W**

Wave, evanescent, 88, 361  
 Waveguide, filled, 100, 393  
 Waveguide Modes as an Interference Effect, 98, 389  
 Waveguides, square and triangular, 387  
 Waveguide with a moving end, 111, 429  
 Wave packet, quasi-Gaussian, 61, 295  
 Wave packet, square, 68, 77, 307, 333

Waveplate, [90](#), [370](#)

Wave propagation in a conductor, [88](#), [361](#)

Wave propagation in a filled waveguide,  
[100](#), [393](#)

Waves, surface, [93](#), [376](#)

Whistler waves, [92](#), [374](#)