SPACETIME PHYSICS

TAYLOR / WHEELER

A Brief, Readable Exposition
of Modern RELATIVITY THEORY
Illustrated and Amplified
by a Wealth of
PROBLEMS, PUZZLES, and PARADOXES
and Their Detailed Solutions

Selected Physical Constants

Speed of light in a vacuum	$c = 2.997925 \times \begin{cases} 10^8 \text{ meters/second} \\ 10^{10} \text{ centimeters/second} \end{cases}$
	$c = \begin{cases} 1 \text{ meter of distance/meter of light-travel time} \\ 1 \text{ centimeter of distance/centimeter of light-travel time} \end{cases}$
Gravitational constant	$G = 6.670 \times \begin{cases} 10^{-11} \text{ meter}^3\text{/(kilogram-second}^2\text{)} \\ 10^{-8} \text{ centimeter}^3\text{/(gram-second}^2\text{)} \end{cases}$
Planck constant	$h = 6.6256 \times \begin{cases} 10^{-34} \text{ kilogram-meter}^2\text{/second} \\ 10^{-27} \text{ gram-centimeter}^2\text{/second} \end{cases}$
Quantum of angular momentum	$\hbar = 1.0545 \times \begin{cases} 10^{-34} \text{ kilogram-meter}^2\text{/second} \\ 10^{-27} \text{ gram-centimeter}^2\text{/second} \end{cases}$
Boltzmann constant	$k = 1.38054 \times \begin{cases} 10^{-23} \text{ joule/degree Kelvin} \\ 10^{-16} \text{ erg/degree Kelvin} \end{cases}$
Elementary charge	$e = \begin{cases} 1.60210 \times 10^{-19} \text{ coulombs} \\ 4.80298 \times 10^{-10} \text{ esu or (gram centimeter}^3\text{/second}^2\text{)}^{1/2} \end{cases}$
Electron rest mass	$m_e = 9.1091 \times \begin{cases} 10^{-31} \text{ kilogram} \\ 10^{-28} \text{ gram} \end{cases}$
Electron rest energy	$m_ec^2 = 8.1869 \times \begin{cases} 10^{-14} \text{ joules} \\ 10^{-7} \text{ ergs} \end{cases}$ $= 0.510984$ MeV
Proton rest mass	$m_p = 1.67252 \times \begin{cases} 10^{-27} \text{ kilogram} \\ 10^{-24} \text{ gram} \end{cases}$
Proton rest energy	$m_pc^2 = 1.503186 \times \begin{cases} 10^{-10} \text{ joules} \\ 10^{-3} \text{ ergs} \end{cases}$ $= 938.232$ MeV
Mass of the earth	$M_\oplus = 5.977 \times \begin{cases} 10^{24} \text{ kilograms} \\ 10^{27} \text{ grams} \end{cases}$
Radius of a sphere having the same volume as the earth	$R_\oplus = 6.371 \times \begin{cases} 10^6 \text{ meters} \\ 10^8 \text{ centimeters} \end{cases}$
Mean distance of the earth from the sun = "astronomical unit"	$AU = 1.495985 \times \begin{cases} 10^{11} \text{ meters} \\ 10^{13} \text{ centimeters} \end{cases}$
Mean speed of the earth in its orbit about the sun	$v_e = 29.8$ kilometers/second
Mean distance of the moon from the earth	$3.84 \times \begin{cases} 10^8 \text{ meters} \\ 10^{10} \text{ centimeters} \end{cases}$
Mass of the sun	$M_\odot = 1.989 \times \begin{cases} 10^{30} \text{ kilograms} \\ 10^{33} \text{ grams} \end{cases}$
Mean radius of the sun	$R_\odot = 6.9598 \times \begin{cases} 10^8 \text{ meters} \\ 10^{10} \text{ centimeters} \end{cases}$

Conversion Factors

1 second $= 2.997925 \times \left\{ \begin{matrix} 10^8 \text{ meters} \\ 10^{10} \text{ centimeters} \end{matrix} \right\}$ of light-travel time

1 meter of light-travel time $= 3.335640 \times 10^{-9}$ second

1 centimeter of light-travel time $= 3.335640 \times 10^{-11}$ second

1 year $= 3.156 \times 10^7$ seconds $= 9.460 \times \left\{ \begin{matrix} 10^{15} \text{ meters} \\ 10^{17} \text{ centimeters} \end{matrix} \right\}$ of light-travel time

1 kilometer = 0.6214 mile

1 electron-volt $= 1.602 \times 10^{-19}$ joule $= 1.602 \times 10^{-12}$ erg

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Spacetime Physics

A Series of Books in Physics

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Spacetime Physics

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Preface

The advances of the nineteenth century in mechanics, electromagnetism, and the properties of matter have been drawn together into a harmonious whole by the great modern unifying principles of relativity and the quantum. Teaching introductory physics courses unaided by the power of these simplifying concepts is like doing long division laboriously with Roman numerals, unaware of the advantages of Arabic symbols.

Developed for the first month of a freshman physics course, *Spacetime Physics* exemplifies today's readiness to place the simplifying discoveries of Einstein and others at the beginning of the study of physics rather than at the end. The book provides an elementary, yet sound and rigorous, introduction to relativity and brings closer the day when the student of physics will be as much at home with the geometry of spacetime as the student in an earlier century was with Euclidean geometry.

Preliminary drafts of this book have been used in freshman classes in several institutions, in intermediate classes, and in summer conference courses for college teachers. Calculus employed is minimal (the concept of velocity) and can easily be supplied by the instructor if it has not been covered in an earlier or a concurrent mathematics course. More than one hundred exercises—many of them solved in detail—analyze a wide variety of current experiments, probe the observational and philosophical foundations of relativity, and provide a rich menu of puzzles and paradoxes. A few of the advanced problems (marked with asterisks) require calculus and should prove challenging to upperclass students.

Chapter 1 develops the simplest and most essential properties of spacetime. Apparent paradoxes in spacetime geometry are seen to melt away on comparison with analogous "paradoxes" in the everyday Euclidean geometry of space. A close tie is established between the geometry of spacetime and the physics of freely moving objects.

Chapter 2 forgoes traditional—and premature—use of the Newtonian equation $F = ma$ and turns instead directly to the principle of action and reaction and the law of conservation of momentum. Momentum and energy, bursting the bounds of the Newtonian vision, reveal themselves as parts of a larger unity that also encompasses rest mass.

Chapter 3 discusses the limits of special relativity and the domain of general relativity. The book concludes with a panorama of physics as seen from the spacetime viewpoint—a path to the understanding of physics that is truly simple, because "that is how the machinery of the world really works."

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